NITROGEN FERTILIZATION OF PASTURE AND FORAGE GRASSES IN HAWAII

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HAWAII AGRICULTURAL EXPERIMENT STATION • UNIVERSITY OF HAWAII

BULLETIN 124 SEPTEMBER 1960

Grade beef animal on lightly fertilized panicum pasture under high rainfall (76 inches), Halehaku Field, Maui, Vegetation Zone D1. Compare this growth with heavy growth, shown on cover. (Photo by M. Takahashi.)

COVER PHOTO

Grade range cattle on heavily fertilized panicum pasture under high rainfall (76 inches), Halehaku Field, Maui, Vegetation Zone D1). (Photo by M. Takahashi.)

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ACKNOWLEDGMENT

Grateful acknowledgment is made to: K. Murakami, Farm Manager, and staff for supervision of the experiments at the Haleakala Branch Station; members of the former Department of Agricultural Chemistry and Soils for nitrogen determinations: Teruo Togashi, Annie Tom Chang, Yoshinori Kanehiro, Martha N. Nakamura, and Hiromu Matsumoto.

Appreciation and thanks are also tendered to the managements of Haleakala Ranch, Kaupo Ranch, Keaau Ranch, Koolau Dairy, and Pacific Chemical and Fertilizer Company for use of land and assistance at several outlying field experiments.

Grateful thanks are also rendered for clerical assistance to Mrs. Betty Someda, Mrs. Helen Nakaoka, and Mrs. Audrey Tang.

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INTRODUCTION

The use of commercial fertilizer in the production of forage in Hawaii is of relatively recent origin. However, the use of natural materials such as barnyard manure for the production of forage cut for soilage and fed to work stock or dairy cattle has been a common practice for many years. The concurrent development of pen-feeding dairy cows, the ready acceptance of heavy yielding forages such as napier, and the spectacular rise in land values resulting in mounting pressures for increased production during and subsequent to World War II facilitated the wide acceptance of commercial fertilizers in the production of soilage crops. Pasture fertilization, by contrast, has found little acceptance except in the limited areas where pasture irrigation by portable overhead sprinkler systems has been developed since 1952. Essentially few ranchers or farmers currently practice pasture fertilization. Nevertheless, considerable interest in the potentials of pasture and range improvement is gradually being generated by rising land rentals and the pressure for increased production.

LITERATURE REVIEW

Experimentation with pasture fertilization, contrasted with the delay in commercial use of the practice, goes back a considerable period in Hawaii agriculture. The first recorded attempt at range improvement, begun in 1902 at Princeville Ranch, Kauai, and involving several hundred acres, mentions the testing and introduction of improved forages such as buffalograss *(Stenotaphrum secundatum)*, paspalum *(Paspalum dilatatum)*, orchardgrass *(Dactylis glomerata)*, and carpetgrass *(Axonopus compressus)*, but makes no mention of any fertilizer application *(19)*. The first fertilizer field tests on forage crops were apparently undertaken in 1917 with alfalfa at the HAES Haiku Demonstration Farm, Maui, in which increased yields were obtained for phosphorus equivalent to 500 pounds of superphosphate per acre on new land cleared of guava *(15)*. By comparison, sugar cane was fertilized as early as 1879 at Onomea, Hawaii, while pineapples were first fertilized at the Haiku Demonstration Farm in 1915 *(20)*. Subsequently up to World War II, numerous field fertilizer tests on forages were undertaken by the Hawaii Agricultural Experiment Station as well as cooperatively with interested ranchers and other private organizations. The results of these experiments showed that an initial response could be had to phosphorus for the first year. Little or no response was noted for potassium or other mineral elements. Nitrogen in general gave the largest response on grasses but had little residual effect beyond the treated crop or ratoon. In retrospect it appears that the efforts at crop fertilization prior to about 1950 were foredoomed because of persistent use of penurious treatment rates and ignorance of soil deficiencies in lime and minor nutrient elements.

Hawaii grazing lands comprise some 1.02 million acres, most of which is unimproved range. The carrying capacity of this range, which is devoted mostly to beef cattle production, varies widely, depending on soil, precipitation, plant cover, and topography. Where the soil is thin over bedrock, or where the cover is mostly dense jungle or sparse desert vegetation, the carrying capacity is essentially nil. On the most productive grassy ranges with an equable rainfall the land may support one head of cattle for every 2 or 3 acres, compared to the state average of one head to 6.3 acres. In 1958 the average beef production was 39 pounds liveweight, giving a gross return of $9.56 per acre of rangeland.

The purchase and application of fertilizer materials is a costly investment and is not likely to render a profit except where the native vegetation has been replaced by improved forages, and where favorable soil and climate obtain. For this reason it is probable that only lands capable of producing more than 200 to 300 pounds liveweight of beef per acre per annum or its equivalent in dairy products will fall within the limits of economic fertilization. For the extensive areas of lava flows with thin soils, the rugged mountainous areas, the heavily forested areas, and the prevailingly dry or semidesert areas, the indicated critical growth factors obviously exclude the economic use of fertilizers in crop production.

For the production of forage the Hawaii ranchers are nonusers of fertilizers whereas dairymen use considerable amounts of fertilizer materials, a situation which is somewhat analogous to that existing on the U.S. mainland. According to the first study of its kind, the U.S. National Fertilizer Committee reports that 57 million acres of hay crops in the nation in 1950 received a mean treatment of ⅔ pound of nitrogen, 3 pounds of phosphorus, 2 pounds of potassium, and 656 pounds of lime per acre *(24)*. For the 220 million acres of improved pastures the annual acre rates were ⅓ pound of nitrogen, 1⅓ pounds of phosphorus, ½ pound of potassium, and 24 pounds of lime. In general, the high fertilizer rates were used on vegetables and cash crops such as corn, cotton, tobacco, and potatoes, which received anywhere up to 60 times the rates applied to hay and pastures. Where lime is applied, however, it is nearly always placed on the hay or pasture crop. These data strengthen the conclusion that pasture fertilization is not a general practice and that it is largely restricted to treatments of phosphorus and lime materials. Where nitrogen is used, it is confined chiefly to intensively managed pastures associated with dairy enterprise close to large urban centers.

In Hawaii the pineapple plantations regularly use 200 to 400 pounds nitrogen per acre per ratoon, and about one-third these amounts of phosphorus and one-half these amounts of potassium. The sugar cane plantations use 150 to 600 pounds nitrogen, 0 to 175 pounds phosphorus, and 0 to 600 pounds of potassium per acre per ratoon. Likewise, vegetable growers use heavy rates of fertilization, frequently as much as 150 to 200 pounds each of the major nutrients per acre per crop, with two to seven crops grown in sequence on the same land in the course of a year. Where forage is grown for soilage purposes, chiefly for the use of dairy cows, nitrogen fertilization may run as high as 800 pounds of nitrogen per acre per year in manure and fertilizer combined. Where all manures are returned to the fields, fertilization is reduced to one-third or less of the total materials removed in the cut forage.

Despite the limited use of fertilizers in current range and pasture practices, world-wide interest in the subject is indicated by the many investigations that have been conducted to ascertain the nutritional needs and the economy of fertilization *(2, 4, 5, 11, 18, 22, 28, 31, 35)*. The early studies were preoccupied with yield improvement by means of mineral fertilization. These studies emphasized the use of mineral fertilization with special emphasis on stimulation of legumes in mixed swards as a means of stimulating yields without the use of nitrogen. In later investigations the utilization of nitrogen has received increasing attention in step with the favorable price relationship between fertilizers and livestock products *(1, 30, 34)*.

In more recent studies it has been shown that heavy nitrogen treatments can increase the protein content of grasses to the level found in legumes and that this increase, in addition to increases in total digestible nutrients, may possibly reduce the use of supplemental protein concentrates for milk and beef production *(8, 9, 14, 29, 32, 33, 36, 37)*. Where rainfall limits yields, greater utilization of nitrogen may be attained by the use of overhead pasture irrigation *(8, 9)*.

METHODS

In this report an attempt has been made to bring together results of field experiments on nitrogen fertilization on various pasture crops conducted on Oahu, Maui, and Hawaii. The experiments reported have been conducted over a period of time extending back to 1938 and cover a wide range in environmental conditions and considerable variation in experimental procedure. Insofar as possible, the large body of forage yield data has been subjected to statistical analysis and the validity of the results established. In several instances lack of replication or the design of the experiment precludes statistical analysis. Where treatments have been applied at three or more rates *(12)*, the resulting yield data provided the basis for an adjusted yield curve by means of the exponential equation, $y = M(1 - R^x)$. To further facilitate the interpretation of diverse field data all results are reported on the annual acre basis. The field site description and specific methods of procedure are discussed in detail for each experiment in the section on experimental results.

Chemical analyses based on standard methods are reported on material dried at 70° C. unless otherwise indicated.

EXPERIMENTAL RESULTS AND DISCUSSION

Kikuyu Pasture Fertilization, Paanui, Haleakala Ranch, Maui

The performance of a renovated stand of kikuyu grass *(Pennisetum clandestinum* Hochst.) fertilized with different levels of nitrogen is reported for four ratoons of mowed forage, covering a period of about 1½ years from 1947 to 1949 (table 1 and figures 1 and 2). The objectives of the experiment were to increase forage production and to extend the grazing period in the dry season by increasing the carry-over of forage.

The site of the experiment is 1 mile mauka of Haleakala Ranch headquarters, at 2,300 feet above sea level. The soils of this area belong to the Waimea fine sandy loam, sloping phase, a member of the Reddish Prairie Great Soils Group *(3)*. Only moderately leached, the soils are normally well supplied with bases. The most likely fertilizer response on these soils is to nitrogen. Due to the proximity to bedrock and the steep slope gradient, these soils are poorly adapted to cultivation and their best use appears to be grazing. They are among the best pasturelands in the Islands from the standpoint of yield and quality of the forage.

The Waimea soils occur mainly in vegetation zone C2 *(25)*, the natural vegetation being a mixed open forest of ohia lehua, koa, and eucalyptus, with the principal forage species being bermuda, kikuyu, rattail, natal redtop, spanish clover, and transient legumes such as white clover and bur clover.

The mean annual rainfall ranges from 30 to 50 inches, with 3 to 4 months of the summer commonly receiving less than 1 inch per month; and there are drought periods of moderate to severe intensity in most years. The mean annual temperatures range from 60° to 72° F. and are thus about 10 degrees cooler than at sea level.

The kikuyu fertilizer experiment was initiated on an established stand of kikuyu that had been renovated by plowing 6 months previously. After removing the top growth by mowing, the nitrogen fertilizer in the form of ammonium sulfate was broadcast over the test plots. The treatments consisted of four nitrogen levels and a check, replicated five times. Subsequent fertilization was applied in two equal portions, one in March and the other in October. Yields were determined from the mowed forage when the kikuyu measured 4 to 6 inches high and had attained optimum growth for pasturage.

Past experimentation has shown that there is fair to good correlation between yields obtained by clipping and grazing performance. In general, about 30 to 70 percent of the total forage available for grazing, as determined by clipping, is not eaten by grazing animals. Part of this rejected forage is wasted by trampling and pollution but the major portion is probably too unpalatable, being stemmy and woody. The rejected residue constitutes a valuable nutrient reservoir that greatly assists recovery and regeneration of new production. For many forage species a more or less constant grazing residue is in fact necessary for sustained high production and for maintenance of the stand and sward. Little residue in such cases is a sign of overgrazing and indicates future reduced yields. For forage species, such as kikuyu, bermudagrass, or those which largely regenerate from new shoots arising from the plant crown, close or complete grazing or periodic mowing is desirable, as cattle will confine their grazing to new growth and will ignore old growth and mixed old and new forage. Likewise, the proportion grazed varies with season, location, and other factors that affect palatability of forage.

The yield performance data show statistically significant responses to nitrogen at the higher nitrogen rates. The reduction in protein percentage associated with nitrogen treatment shown in this test is contrary to the usual experience in grass fertilization, and no ready explanation for the phenomenon is at hand. However, it is probably associated in this experiment with the fact that the response to fertilization shows little sign of falling off even at the maximum 320-pound nitrogen treatment.

Illustrated in figure 2 is the yield performance of kikuyu, showing the yield per acre per day for the various nitrogen levels at different seasons of the year. Rainfall was measured weekly at a rain gauge at the test site. The most noteworthy observation is that the daily kikuyu production is fairly constant. For 1948, there was a drought period from May to October which slowed growth for about 4 months. Heavy fertilization produced marked yield increases throughout all periods of the experiment. Whether the increased yield for liberal nitrogen fertilization gives a satisfactory carry-over into the dry season remains to be demonstrated. It is evident, however, that nitrogen fertilization maintained increased production throughout the drought period at a yield level up to three times that of the check.

The overriding effect of lack of available moisture for growth appears to have masked any positive response to seasonal variation in hours of daylength and associated factors. The daily yield curve is normal for situations where moderate summer droughts occur and where irrigation is not available. Where adequate water is available the vegetative yields normally follow the daylength curve, being highest when days are long and minimal when sunlight hours are short. A seasonal summer drought thus tends to produce a flattened yield curve or a curve with two peaks, one in the late fall and the other in late spring when fairly adequate amounts of both rainfall and sunlight bring about maximum growth and yield.

On the basis of the yields and cost for nitrogen shown in table 1, it appears that nitrogen treatment of kikuyu rangeland similar to the test area may be profitable, if the increased production has a value of about $20 or more per ton of dry matter and for rates of nitrogen up to 300 pounds per acre per year.

Panicum Soilage Fertilization, Koolau Dairy, Oahu[1]

The performance of panicum or paragrass *(Panicum purpurascens* Raddi.) in an old established stand when topdressed with N, P, K, and lime is shown for four cuttings made at 2-month intervals from April to December, 1942, at Koolau Dairy, Oahu (table 2).

The test area is situated on Kaneohe silty clay, gently sloping phase *(3)*. These soils are severely depleted in basic materials such as calcium, magnesium, and potassium, resulting in a strongly acid reaction, usually between pH 4.5 and 5.5.

The Kaneohe soil family occupy the high terraces on the windward side on the four main islands at elevations ranging from near sea level to 3,000 feet. The mean annual rainfall is 50 to 80 inches. From 1 to 3 months of the year normally receive less than 1 inch of precipitation per month, resulting in annual periods of drought of varying severity. The prevailing undisturbed plant cover is that of vegetation zone C transitional to zone D, consisting of dense stands of guava and ohia interspersed with open patches of various ferns, hilograss, and bermudagrass, and scattered spanish clover and sensitive plant *(25)*.

The panicum fertilizer experiment, designed to continue over a period of 2 years or more, was terminated before this time by the outbreak of World War II. The eight fertilizer treatments were applied in four replications. All materials were broadcast at the start of the experiment except for the nitrogen which was divided in three parts, one-third being applied after every other harvest. The four cuttings reported thus received two-thirds of the total nitrogen planned for the year.

The reported yields represent the forage used in pen-feeding dairy cattle, and provide a fair basis for estimating the utility of fertilizing unirrigated panicum used as a soilage crop on the Kaneohe soil series.

[1] The field phase of the panicum experiment at Koolau Dairy was conducted by Pacific Chemical and Fertilizer Company of Honolulu.

The dry matter yield data show significant responses to nitrogen only, while no statistically significant response is shown for the phosphorus, potassium, and lime treatments. In other words, no positive benefit was obtained for any treatment other than nitrogen. It is possible that had the test continued over a period of years some of the nutrients that at first failed to do so, would have given yield responses, following progressive removal of nutrients by the forage.

The panicum yields and corresponding costs for the fertilizer treatments shown in table 2 suggest that nitrogen treatments up to 200 pounds per acre per year may produce dry matter yield increases at $4 to $12 per ton.

Panicum Pasture Fertilization, Haleakala Branch Station, Maui

The performance of panicum (*Panicum purpurascens* Raddi.) in a pasture experiment at the Haleakala Station, over a 5-year period, 1947 to 1951, when treated with different rates of nitrogen in the form of topdressed ammonium sulfate fertilizer, is presented in tables 3 to 5 and figures 3 and 4. The experimental area is situated on Makawao silty clay loam, gently sloping phase, a member of the Honolua family of Humic Latosols *(3)*. The Makawao series is confined to the vicinity of Makawao on the slopes of Haleakala at elevations from 1,200 to 2,800 feet above sea level. The Makawao soil is quite acid throughout the profile, the pH usually ranging from 4.0 to 5.5, the content of bases is low, and fixation of added phosphorus is high. This would suggest that these soils might give economic returns for fertilization with N, P, K, and lime, for crops having high nutritional requirements.

The undisturbed vegetation is forest, predominantly ohia lehua, eucalyptus, hala, and guava. Open areas grow various ferns, sedges, hilograss, ricegrass, rattail, and yellow foxtail. Extensive improved areas consist of nearly pure stands of kikuyugrass range. Classed as C, the narrow belt comprising this zone is purely transitional between the adjacent larger D and B vegetation zones *(25)*.

The 22-year annual rainfall at the gauge at the site of the experimental paddocks averaged 55.0 inches. Commonly, 1 or more months each year receives less than 1 inch of rain. Rainfall is highly variable and drought conditions of varying severity occur about 1 year out of 2, usually in the summer period or from May to September. A high degree of cloudiness occurs, especially in the winter season, when most of the rain is received. Temperatures range between a day maximum of 82° F. to a night minimum of 48° F.

A wide variation exists in the annual performance of panicumgrass in this experiment which is primarily a reflection of variation in rainfall, which during the 5-year period of the experiment ranged from 37 inches in 1951 to 93 inches in 1948. Differences in distribution of the rainfall were also important, and especially serious when drought periods extended beyond 2 to 3 weeks in duration.

The nitrogen fertilizer experiment was begun on an old stand of panicum which formerly received moderate amounts of complete fertilizer. Each of the four test treatments, viz. check, 30, 60, and 120 pounds of nitrogen per grazing period in the form of ammonium sulfate, 20 percent nitrogen, comprised a single ¼-acre paddock. The respective treatments were applied broadcast at the indicated acre rates, at the close of each grazing period. Amounts per year therefore varied with the number of grazings during the year, which ranged from two to six. Each treatment was grazed when the yield attained optimum growth for grazing, which usually occurs just before the grass initiates the flowering stage. Sufficient cattle were placed in the paddocks to consume all the grazeable forage in a matter of 5 to 20 days. Resting periods between grazings varied from 30 to 165 days, depending on rainfall and treatment. The cattle used in the test were long yearling dairy heifers weighing 400 to 700 pounds.

Grazeable forage as used in this report is defined as all new stems and leaves subtending the old growth remaining from previous grazings. The amount of old growth to retain, chiefly woody stems and sheaths, which constitute a suitable reservoir for new growth, has been established empirically from practice. The optimum residue level will vary among forage species, sites, and seasons, and is further modified by forage palatability, and by the degree of discrimination shown by the grazing animals. Where new growth arises from the lower stem or crown of plants, little residue needs to remain. Where new growth is chiefly from lalas[2] at the upper portion of more or less permanent stems, it is evident that considerable residue must remain or yields will suffer. Crider *(6)*, working with mainland temperate zone grasses, states that intensity of grazing that leaves less than 50 percent of the forage is too severe and will bring about progressive depletion of the stand of most forage plants and is therefore uneconomic.

The yields reported in this experiment are based entirely on the grazeable portion or new growth which was plucked by hand from randomized replicated plots in each paddock at the start of each grazing period. Inasmuch as the number of grazings varied between treatments and from year to year, the test materials applied per year ranged from two to six applications. Likewise, the carrying capacity in cow-days[3] per acre ranged from a low of 77 for the check treatment in droughty 1949 to a high of 416 cow-days for the 120-pound nitrogen rate in wet 1948, the apparent limiting factor being rainfall.

The amount of meat, milk, or other similar forms of production is undoubtedly the best criteria of grazing performance and the evaluation of fertilizer treatments. However, in the current experiment the acute lack of available land limited the size of the paddocks to ¼-acre and to single replications which provided only a few days of grazing. Also, the same cattle were moved from one treatment to another as grazing was completed and this, coupled with the normal fluctuation of the animal weights, precluded the assessing of reliable weight gains. Consequently, the best measure of the value of the nitrogen fertilization in this test is given either by the yield of panicum dry matter or by the carrying capacity reported as the number of cow-days of grazing produced by each treatment. The dry matter yield appears to be the most reliable of the two indices.

A complicating factor in this series of experiments was the severe loss of palatability and rejection of forage at the higher nitrogen treatments, which obviously reduced the carrying capacity. Loss in palatability with heavy fertilization usually results from a severe imbalance in the nutrient uptake of the forage. This condition is especially noticeable in urine spots in pastures in which excessive

[2]A lala is an axillary shoot developing above the node of woody stemmed grasses or other plants.

[3] A cow-day is defined as the grazing capacity per acre per 1,000-pound liveweight units of any specific weight class of cattle during a 24-hour period.

absorption of nitrogen by the plants results in a succulent rank growth of forage highly unpalatable to grazing livestock.

The results of the grazing test are shown as 5-year averages in table 3.

The 5-year test shows a check dry matter yield of 4,400 pounds per acre and 137 cow-days of grazing per year. Nitrogen treatment at the rate of 114 pounds per acre per year raised the dry matter yield to 12,450 pounds or nearly three times that of the check, the yield increase per ton of dry matter costing $4.25 for the fertilizer. The carrying capacity, however, increased only by 119 percent over the check. Nitrogen treatments at 252 and 528 pounds per year increased the yields only slightly over the 114-pound rate and appear to be uneconomical for beef production. However, by separating the 5-year test period into a wet and dry period, a more specific interpretation can be obtained.

Thus, the 5-year experiment encompassed two distinct periods based on adequacy of rainfall for pasture production, which presented an excellent opportunity to compare nitrogen fertilization response under extremely different rainfall conditions (table 4). It is quite generally held that pasture fertilization of any kind during periods of less-than-optimum rainfall or during prolonged drought is impractical and a needless extravagance. That this point of view may not be entirely correct is indicated by the results for the two droughty seasons of this experiment, 1949 and 1951. Based on records from a rain gauge at the test site, these 2 years had a total of 29 and 37 inches rainfall, respectively, of which 5 and 4 inches fell during the 5-month period May to September. Only the champion drought of 1953 with a total of 24 inches rainfall, of which 5 inches fell during the same 5-month period, can equal in severity the 2 years of record, extending back to 1938. During this entire period only 1946, 1949, 1951, 1952, and 1953 received less than 6 inches of rainfall for the May-to-September period, whereas the 1938–60 average for the 5-month period is 11.3 inches. In comparing the two rainfall periods it will be noted that drought resulting from less than half average rainfall during the critical May-to-September period caused yield and grazing losses of lesser magnitude. Dry matter yields were reduced to about 60 percent of the wet years, and carrying capacity was reduced to about 55 percent of the wet years. This suggests a small reduction in grazing efficiency as drought severity increases. Possibly the digestibility of the drought forage is less than that of forage grown with adequate rainfall. There is no apparent change in the percent of protein in the test forage for the two rainfall periods.

Comparison of the yield capacity and costs of nitrogen fertilization shown in figure 3 and recorded in table 4 as cost of N for DM increment indicates that good returns for fertilization can be obtained even in the driest years. For the wet rainfall year with more than 11 inches of May-to-September rain, it probably will be profitable to apply nitrogen at rates up to about 150 pounds per acre per year. For the dry years with rainfall below 11 inches in the May-to-September period, nitrogen treatment appears practicable up to about 75 to 100 pounds. In each case this is automatically accomplished by applying 30 to 35 pounds of nitrogen after each grazing, as was done in the current experiment.

The current experiment also permits an assessment of the relative efficiency of nitrogen during wet years and during drought. The recovery of the added nitrogen in the form of crude protein for the two rainfall conditions is shown in table 5 and figure 4. It will be noted that the indicated degree of recovery of the added nitrogen, ranging from 117 to 57 percent, is extremely high for any type of nonleguminous forage. Panicum appears to have an exceptional ability to utilize nitrogen and convert it into plant proteins. The manner of this protein synthesis and the distribution of the various amino acids in the crude protein is a subject for further study. Compared to the various kikuyu and napier grasses described elsewhere in this report, which on heavy nitrogen treatment produce a twofold protein increase or less, panicum is capable of at least a threefold increase based on the mature vegetative growth. For most forage grasses the recovery of added nitrogen is usually in the range of 20 to 50 percent. The nitrogen recovery curves indicate that at low nitrogen treatment rates the nitrogen efficiency is nearly the same in dry and wet years. It is apparent, however, that lack of moisture in drought years drastically reduces nitrogen recovery at rates above 300 pounds nitrogen per acre per year. In the wet year, however, recovery of nitrogen is still satisfactory up to treatment rates in excess of 400 pounds nitrogen. Panicum is here revealed as exceptional in its ability to efficiently combine high yield with high protein content in response to nitrogen fertilization.

It will also be noted that during drought, the lower nitrogen treatments recover more nitrogen than is added. This apparent overdraft of nitrogen is probably a temporary depletion of residual supplies in the soil which is restored later in wet seasons.

Napier Soilage Fertilization, Keaau Ranch, Hawaii

One year's performance of an old stand of napiergrass (*Pennisetum purpureum* Schumach), treated with various fertilizers at Keaau Ranch, Hawaii, from July 1936 through September 1937, is reported in table 6 and figure 5. The field test was established to supplement the meager information available on fertilizer response by napier under wetland or rainforest conditions.

The soil of the experimental site is Olaa stony silty clay, gently sloping phase, and belongs to the Hydrol Humic Latosol group of soils *(3)*. The soil is developed on a thin variable cover of volcanic ash and rubble overlying lava rock at a prevailing depth of 10 to 20 inches. The top soil, 0 to 10 inches in depth, is a friable, dark reddish brown silty clay loam, high in organic matter, mixed with rock fragments comprising 20 to 50 percent of the total volume. The subsoil extending from 10 to 15 inches in depth, is yellowish red silty clay loam filling the spaces between numerous rock fragments. The soil reaction ranges from pH 5.2 to 5.8 in both horizons. Locally, rock outcrops are quite common. The soil is extremely stony, which interferes with tillage. The soil is low in available major nutrients and responds to heavy treatment of complete fertilizer. Minor element deficiencies associated with soils high in organic matter occasionally occur.

The Olaa series is a young soil occurring on geologically recent lava flows at elevations ranging from sea level to 2,500 feet. The annual rainfall ranges from 100 to 200 inches. The area lies entirely in vegetation zone D1 *(25)*. The undisturbed cover is heavy jungle forest but presently is largely cleared, and the land is devoted to sugar cane production or general farming. Yields of cane vary from 40 to 60 tons of fresh material per acre per crop when heavily fertilized and have a sugar turnout of about 1 to 8. Yields of forage are generally medium but the quality and palatability are inferior, and the dry matter and mineral content are low. Much of the Olaa series is marginal for sugar cane production and may eventually transfer to some other use.

Meteorological data covering the 15-month period of the experiment, July 1936 through September 1937, showed 115 and 124 inches rainfall, respectively, for the 2 years or about 25 inches in excess of the previous 10-year average. The number of rainy days per month was 27 days, which of course implies overcast skies and very little clear sunshine.

The experiment was established on an old stand of napier some 6 or 7 years old. Previous fertilization had been 30–5–30 (pounds N–P–K) material per acre in 1935. The six treatments in the test were replicated five times, the materials being distributed over the row immediately after harvest. The P and K materials were applied in two equal portions at the start of the test and after the fourth ratoon. Nitrogen was topdressed at the start of every ratoon at the rate of 32 and 64 pounds per acre for the N and N_2 treatments, respectively.

The results show that statistically significant yield increases were obtained with all treatments over the check. It will be noted that the greatest responses were to nitrogen, followed by potassium and phosphorus. The increases for nitrogen are nearly linear for the treatment range of 0 to 320 pounds of nitrogen per acre, indicating that this element is needed at still higher rates. Fertilization under the conditions of this test does not appear to be profitable as shown by treatment costs of $15 and up per ton of dry matter yield increase.

The experiment, being harvested at regular short intervals, provided an excellent exhibit of the association of growth and yield with seasonal daylength, temperature, and related factors (figure 5). While the yields of dry matter per acre per day are only 25 to 50 percent of satisfactory performance, the response of growth to seasonal differences in daylength is nevertheless definite and unmistakable. Younge and Takahashi *(39)*, working with fertilized, irrigated alfalfa at the Poamoho Station, found the long-day yields in June to be five times those of the short-day yields in December, the respective yields being about 100 and 20 pounds of dry matter per acre per day. In this napier experiment the June yields are about 70 pounds and the December yields 5 pounds of dry matter per acre per day, suggesting that napier is even more sensitive to daylength differences than alfalfa. Also, it is well to note that in all probability, in the napier test all major nutritional needs were not satisfied, and that the daily growth response could be somewhat different at higher or different treatments. However, despite the diverse nutrients used in this experiment, the yield curves are strikingly similar to those reported for alfalfa, indicating daylength or some associated factor is highly compulsive in regulating growth of napier.

Subsoiling and Nitrogen Fertilization of Grazed Napier, Haleakala Branch Station, Maui

The effect of annual subsoiling or deep tillage, coupled with nitrogen fertilization of grazed napier, was studied at the Haleakala Station over the 4-year period March 1945 to May 1949 (table 7 and figure 6). The soil of the experimental area is Makawao silty clay loam, gently sloping phase, which has been described elsewhere under the Haleakala Station panicum experiment. In the current test, napier No. 3418 was planted in 4-foot rows and topdressed with various rates of nitrogen in the form of ammonium sulfate for each of ten grazings. The experimental design involved six fertilizer treatments replicated eight times. Each replication comprised a block, and four of the replications or blocks were retained as control and the remaining four blocks were subsoiled annually. For this operation a tractor-drawn subsoiler was run twice down each row just outside the crowns, immediately following grazing and mowing of the uneaten stalks. Yields were taken by harvesting two rows 18 feet long immediately before each grazing when the grass had attained a height of 5 to 7 feet and before dry leaves extended more than one-third up the stalk from the base. After plot yields were secured the whole experiment was subjected to grazing. As soon as grazing was completed, the remaining stalks were mowed and fertilizer was applied. This method of grazing obviously resulted in some transfer of residual nutrients among the various plots, which in turn influenced later yields. However, it is evident that such nutrient translocation would tend to reduce yield differences between treatments; hence, any resulting error would be on the conservative side and, therefore, response to treatment presumably actually would be greater than indicated by the yield data.

The rainfall throughout the 4-year period of the experiment was average or above, except for the year 1946. Rainfall throughout the May-to-September low rainfall period for 3 years exceeded 10 inches, well above the critical limit, while in 1946, 4 months received less than 1 inch of rain per month. As a result of favorable rainfall distribution for the test period, the napier produced adequately.

The yield data indicate that annual subsoiling produced no significant yield improvement and, if anything, was detrimental. On theoretical grounds deep tillage could be considered beneficial in pruning of roots and splitting of the crown of the plant to reduce a sodbound condition, assuming this condition is detrimental. Subsoiling is essentially an operation in which some of the roots and crowns of plants and the adjacent soil surface are broken up, resulting in partial destruction of the plants. As shown by the yield data, it is doubtful if subsoiling or deep tillage to growing crops will produce yield increases except under unusual circumstances. And it is concluded that a sodbound condition in itself is not detrimental to forage production. Where furrow irrigation of napier is practiced it may be necessary to reshape the furrows from time to time in order to restore adequate water flow, in which case the unavoidable tillage involved is usually shallow and root and crown damage is held to a minimum. Damage of this type can be reduced by performing the operation when soil moisture conditions are good or by immediate irrigation after the operation is completed. Carried on during a drought and delaying irrigation by even a few days, results in severe crop damage, retardation of growth, and yield loss.

The yield data show statistically significant response of napier to nitrogen treatment. For nitrogen at rates up to 100 pounds per acre per year, the cost for the treatment is less than $14 per ton of dry matter. Whether nitrogen fertilization is profitable elsewhere under conditions similar to the test would depend on the market demand for napier forage.

The addition of the PK treatment to nitrogen at the rates used was not statistically significant. And for the yield increase shown it is not profitable inasmuch as the PK added about $75 per acre to the annual fertilizer cost while the yield increased less than 1 ton in dry matter.

The yields of napiergrass failed to exhibit any apparent seasonal fluctuation which might be related to differences in daylength or associated factors. Any seasonal variations that did occur were effectively masked through equalization of short and long daylengths during the long growing periods, which ranged from 110 to 217 days, with an average of 152 days.

With respect to quality of the napier forage the yield data show that there was a small but not statistically significant increase in protein with increased nitrogen fertilization, the protein content of 5.60 percent in the check increasing to 6.25 percent for the highest rate of nitrogen. The subsoiling treatment evidently had no effect on protein accumulation, as the protein values for the various tillage treatments closely followed the corresponding nonrenovated treatments. The total spread for all treatments, ratoons, and renovations was from 4.12 percent to 6.92 percent protein.

Grazing Stage and Nitrogen Fertilization of Napier, Haleakala Branch Station, Maui

The results of a napier grazing experiment on four levels of nitrogen fertilization and two methods of grazing for the 4-year period 1949–52 are presented in tables 8 and 9 and figure 7. The test was laid down in duplicate ¼-acre paddocks on a new planting of napier No. 3418, planted in double rows 3 feet within pairs and 6 feet between pairs. The soil of the test area is Makawao silty clay loam, sloping phase, as described elsewhere under the Haleakala Station panicum experiment. Prior to planting, a single treatment of 600 pounds per acre each of superphosphate, 9 percent P (20 P_2O_5), and potassium sulfate, 44 percent K (52.5 K_2O), was applied in the furrow. Nitrogen in the form of ammonium sulfate, 20 percent N, was added in the furrow for the first treatment at the required rates, and was sidedressed on the row for all subsequent applications after each grazing. Inasmuch as the number of treatments was governed by the grazing intensity as reflected by the number of grazings, the actual amount of fertilizer nitrogen per year varied with the number of grazings for each treatment. This procedure gears fertilization to production and presumably results in greater efficiency of nitrogen utilization. Previous studies have shown that fertilizer nitrogen has a low residual effect as compared to other major plant nutrients, and the main response is shown in the treated crop with very low carryover for subsequent crops or ratoons. Where application is made with ground equipment, it is evident that it is most convenient and less laborious to time the application following grazing when the crop residue is at a minimum. The cattle used in the test were long yearling dairy heifers weighing initially 350 to 500 pounds each. As in all other Haleakala Station tests they had free access to water, salt, and bonemeal.

In grazing the napier sufficient cattle, usually two or three, were confined in each paddock to complete grazing within a period of 7 days. While weight records were taken throughout the experiment for the purpose of securing average weights, the time spent in each paddock was too brief to result in reliable weight gains and hence was useless as an index of performance. Records were kept also on the number of days each animal spent in a test paddock, and the number of days grazed adjusted to 1,000-pound units is reported as cow-days grazed. There is a variable relationship between carrying capacity in cow-days and the yield of grazeable dry matter. Therefore, the most reliable direct index of the napier grazing provided by this test appears to be the dry matter yield of replicated caged plots in each pasture.

In the grazing of napier, the cattle eat the young leafy portion, leaving the coarse lignified stems. These coarse woody stems, ranging in diameter up to about ½-inch, and arising in clumps up to 20 or 30 in number, give rise at the upper nodes to new shoots and leaves called lala, which in turn provide fresh grazing. The optimum stage of napier grazing is deemed to exist when the prevailing new growth subtends five new leaves and associated stem growth. Normally, a stem will be productive, through primary and lala growth, for a year. New basal shoots replace the older ones, the period of major development of the new stems being in the spring. The yield of the grazeable forage reported on the dry matter basis was obtained as follows: Five portable cages were distributed at random in each paddock prior to grazing. At the end of the grazing period the new growth in the caged plots was plucked by hand to a stage comparable to the surrounding grazed area. The hand-plucked forage was weighed and samples were taken for laboratory analysis. The average yield of plucked material is considered to provide a good estimate of the yields of grazeable forage actually consumed by the cattle, plus an undetermined variable quantity lost by trampling.

In the current experiment two methods of grazing were carried on in sequence. During the first phase of 3 years, method A, grazing was conducted independently when each paddock had reached the optimum stage. As each treatment obviously followed a different growth schedule, the number of grazings varied and consequently the amount of fertilizer differed for each year (table 8). In method B, which covered a period of about 1½ years, grazing was conducted on a replicate of all treatments simultaneously, when the 40-pound nitrogen treatment reached the optimum stage for grazing (table 9). As recovery following grazing normally is slower with the lower plant nutrient levels, this method would be expected to penalize the check and low fertilizer treatments and favor the heavier nitrogen treatments.

The 4-year period of the current test covered 3 years of drought and only 1 year of adequate rainfall. As shown in table 8, the 22-year average or normal rainfall for the test site is 55 inches, of which 11.3 inches falls in the 5-month period May to September. For this experiment, 1950 was considered a wet year, while 1949, 1951, and 1952 were droughty, receiving only 46 percent of the average rainfall for the critical May-to-September period. Comparison of the carrying capacity, yields of dry matter and protein for the two extremely different rainfall conditions point up the fact that well-managed napier pasture stands supreme among heavy forage producers in maintaining high yields through periods of severe and prolonged drought.

Thus in years when rainfall drops below an average of 1 inch per month in the critical May-to-September period, less than half the normal incidence at the test site, prevailing yield performance is still 80 to 90 percent of wet year production under the A method of grazing napier. In method B, where simultaneous grazing of all treatments was governed by the 40-pound nitrogen treatment, the check yield was below the corresponding treatment in method A, while the higher nitrogen rates produced yields comparable to the wet years. This suggests that additional yield resulted from letting the napier grow and approach closer to maturity where fertilization was high. The higher yield also resulted in a corresponding increase in the number of cow-days grazed. Yield comparisons are shown in figure 7.

In the current experiment the response to nitrogen is a sharply rising, slightly curvilinear function of treatment up to the maximum of 60 pounds of nitrogen per acre per grazing for an average of 4.67 grazings per year or a total of 280 pounds of nitrogen per year. In this experiment, treatment with still higher rates of nitrogen undoubtedly would have brought forth the usual marked curvilinear yield curve. In another experiment on cut napier and the effect of subsoiling it was found that response to nitrogen continued somewhat higher at the heavier nitrogen rates. This would suggest a higher rate of response to nitrogen in the production of soilage than in the production of grazeable material. However, gross yields alone, ignores the composition and the relative feeding values of the two different materials. The grazeable napier in this test was mostly lalas and contained 7 to 10 percent protein, whereas the cut napier in the subsoiling test included all top growth and contained 5 to 6 percent protein (table 7). On the basis of yield plus quality, therefore, managing napier as a grazing crop may be more efficient than treating it as a soilage crop.

Compare now the two methods of grazing used in this test. In the case of all grazing being geared to the stage optimum for the 40-pound nitrogen rate, method B, only the results for the drought period are at hand. The data indicate that the 60-pound nitrogen treatment was favored by the above intensity of grazing while lower rates were penalized, which suggests that the stage originally adjudged to be optimum probably arrived too early and was in fact short of the true optimum for the lower rates of nitrogen. In the current test, delayed grazing gave an increase in yield—which is normal for napier—over earlier grazing. Also, the higher yield was attained without a reduction in protein content. Likewise, the delayed grazing increased the carrying capacity in cow-days over early grazing, the increase being in direct proportion to the grazeable yield increase.

Data on the effect of nitrogen on the quality of the grazeable forage show that, regardless of the stage of grazing the napier, there was a gradual increase in the percent of protein, the increase ranging up to 30 to 40 percent, the crude protein ranging from about 7 percent in the checks to almost 10 percent at the highest nitrogen rate. This increase is considerably higher than that found for the Keaau napier experiment or the Haleakala Station napier subsoiling tests, where the clear-cut forage included considerable stem material. The increase, however, falls far short of the jump in protein from 6.7 percent to 16.8 percent in the nitrogen fertilized panicum at the Haleakala Station. Nevertheless, a 30 to 40 percent protein increase coming on top of a doubled dry matter yield tends to make a forage considerably nearer the desired standard nutritive ratio of 1:8 *(40)*, the nutritive ratio going from 1:15 for the check to 1:10.7 for the 60-pound rate of nitrogen per grazing. The data suggest that the wide nutritive ratios of the unfertilized napier will automatically result in heavy wastage of the nutrients in the unbalanced part of the grazed forage, whereas for the heavy nitrogen fertilization this imbalance and consequent wastage is greatly reduced and therefore may be expected to result in greater economy and greater carrying capacity.

With respect to the degree of efficiency of the added nitrogen, calculation shows that under wet rainfall the nitrogen in the grazeable forage represented about 60 percent of that added in the fertilizer. For the drought periods, method A grazing resulted in 40 to 60 percent recovery, and for method B grazing, the recovery was nearly 80 percent. The higher recovery in delayed grazing, method B, may have resulted from increased crop production over a longer growing period.

Napier Grazing, Kaupo Ranch, Haiku, Maui

The increase in animal weight and carrying capacity from nitrogen fertilization of an old stand of napier was determined in a 2-year grazing experiment at Haiku, Maui, running from April 1950 to July 1952 (table 10).

The soils of the experimental site are classified as Haiku silty clay, gently sloping phase, a member of the Humic Ferruginous Latosols *(3)*. However, it is evident from the general productivity level of the soils in the locality of the experimental site that this area is not representative of the above soil type, but is in fact on the borderline approaching the more productive Kohala soil family lying to the westward in vegetation zone C1. The Haiku soils in many areas are low-grade bauxites and carry high concentrations of titanium near the surface, which tends to form a hardpan and may interfere with root development and drainage. Much of the Haiku area has in the past been in sugar cane and pineapple and a considerable portion has been diverted to other uses because yields of both crops usually were low and the quality was poor. The Haiku soils are notoriously low in fertility and probably require heavy fertilization for satisfactory crop production.

The undisturbed or native flora of the Haiku soils falls in the D vegetation zone *(25)*. Most of the area surrounding the experimental site is either in pineapple or devoted to residential development. On the fairly extensive areas abandoned from pineapple or sugar cane production, now ostensibly in pasture or range, the climax vegetation appears to be a dense stand of ferns, hilograss, ricegrass, and yellow foxtail, most of which is of low palatability to livestock and represents a low carrying capacity.

The grazing test was laid down on an old stand of napier in paddocks ranging from 3 to 3.5 acres in size. Grazing went on simultaneously in paired paddocks, one fertilized and the other serving as a check. During the first year 74 pounds of nitrogen in the form of ammonium sulfate were applied to the treated paddocks after every other grazing, and grazing was adjusted to conditions optimum for the check napier. During the second year 37 pounds of nitrogen were broadcast after every grazing, and grazing was governed by the fertilized napier. Except for 1 month, July 1951, when prolonged drought slowed regrowth and other grazing had to be provided, the animals were shifted from one pair of paddocks to the other pair at about 2-month intervals, each paddock thus being grazed and rested about half the time. Each year a different group of grade Hereford ranch cattle weighing initially from 400 to 600 pounds were used. The same animals as nearly as practicable were grazed continuously on the same series of treatments. Sufficient cattle were placed in each paddock to graze all the forage during the specified periods, or additional animals were added towards the end of the grazing period to complete grazing by the time the alternate paddocks were ready for grazing. Water, salt, and bonemeal were fed free choice to all animals. Following grazing, the fertilized paddocks received the required broadcast fertilizer treatment.

Inasmuch as the experiment involved only one fertilizer treatment and a check, each replicated two times, and since the method of grazing and time and rate of fertilization were different in the 2 years of the experiment, it is impossible to apply any valid statistical treatment to the data and consequently no measure of reliability of the results can be provided. The animal weight gains and cow-days of grazing have been summarized according to whether (A) grazing was governed by conditions optimum for the check and with fertilizer applied after every other grazing, and (B) grazing was governed by the state of the fertilized napier and with fertilizer applied after every grazing, as shown in table 10.

The results of the two methods of grazing and fertilization are quite similar. This similarity may be accidental, however, because of the fact that the weather, rainfall particularly, for the two grazing cycles was dissimilar. As a rule, the stage of growth and condition of each paddock should govern its grazing period independently of other paddocks. This obviously would result in a different schedule for untreated or check paddocks than for the faster growing fertilized paddocks, where recovery after grazing is most rapid.

The results show that 74 pounds of nitrogen applied broadcast per acre every other grazing or half this quantity after each grazing produced gains of 124 and 108 pounds of liveweight per acre per year, respectively, representing a gain over the check of 43 percent. The weight gain difference of 16 pounds in the two methods of fertilization can be attributed mainly to the reduction of 33 pounds or 25 percent less nitrogen during the B cycle of grazing. The increase in cow-days or carrying capacity due to fertilization is 65 and 64 days, respectively, or 51 and 45 percent over the checks.

Inasmuch as actual weight gains and carrying capacity in cow-days are known for this experiment, the return for nitrogen fertilization can be calculated in this test with a degree of precision not possible in other experiments here reported where no weight gain data are presented. Returns based on actual weight gains obviously are more realistic than those based on cow-days when the pay-off is on weight alone. The data show that in the present experiment weight gains ranged from 1.7 to 2.3 pounds per cow-day unit of 1000 pounds, the latter value being about standard for the class of cattle used and the former being definitely below par *(40)*, proving that the cow-day does not correspond to a fixed liveweight quantity. Due to the short grazing cycle of only three grazing periods, the A method of fertilization had two periods fertilized and one period untreated. This means that presumably there was residual fertilizer sufficient for one more untreated period in this cycle, which however cannot be segregated in the results, but which possibly reduced the return for the added nitrogen. The return per 100 pounds of nitrogen was 94 pounds liveweight gain per acre per year. For the B grazing method, where grazing was governed by the condition of the fertilized napier and where fertilizer was applied for each grazing, the weight gain per 100 pounds of nitrogen was 111 pounds. With nitrogen in the solid form priced at $.15 per pound[4] applied in the field, and with liveweight beef at about $.25 per pound, there appears to be a possibility of some profit from nitrogen treatment under conditions similar to this test.

In addition to any direct profit from nitrogen fertilization in this test, it is worth noting that a boost in carrying capacity of 45 to 51 percent, even though resulting in little net return, may under certain conditions be extremely profitable

[4] Nitrogen at $.15 per pound is equivalent to urea, 46 percent N, at $138 per ton.

in other ways, as for example, by carrying over distressed livestock in periods of drought or other disaster and by spreading overhead costs.

It is worth noting also that in the event other nutrient elements were in short supply in this experiment, then evidently the response to nitrogen would be reduced. Thus, if potassium or calcium were in short supply, it is probable that yields were controlled in part by these nutrient elements and not by the supplies of nitrogen alone. The Haiku family of soils are notoriously low in fertility, as already noted, and the presence of some undetermined nutritional deficiency would seem to explain the relatively poor performance in the present tests with or without treatment of nitrogen, and especially the decline in production and carrying capacity during the second year of the experiment.

Renovation and Nitrogen Fertilization of Paspalum Soilage, Haleakala Branch Station, Maui

The effect of various levels of nitrogen fertilization and sod renovation on soilage yield of paspalum or dallisgrass *(Paspalum dilatatum* Poir.), over a 3-year period from April 1946 to June 1949, is presented in tables 11 and 12 and figures 8 and 9. The objective was to determine the effect of renovation on the yield capacity of paspalum. The experiment was initiated on an old stand of paspalum. The experimental design involved six rates of nitrogen replicated twelve times. Each replication comprised a block and six replications arranged alternately with the remaining six blocks were renovated before the start of the experiment and once again after the fourth ratoon in August 1947. Renovation consisted of plowing and discing without subsequent reseeding. Regeneration of the grass stand thus proceeded entirely from the living remains of the old sod.

Nitrogen was applied broadcast in the form of ammonium sulfate, 20 percent nitrogen, prior to the first crop and subsequently following the harvest of each ratoon or to alternate ratoons according to plan. Yields were obtained by mowing the forage when the paspalum had reached the stage considered optimum for grazing. This stage corresponds to the growth and development reached immediately before heading of the grass.

As shown in table 11, the data covered three periods differing in adequacy of rainfall for the production of paspalum. Rainfall records extending back to 1938 are available for the experimental site. The rainfall data show that 1 year of the test period was about average in total rainfall and in distribution of rainfall by monthly periods, here designated as normal. In the normal year at this site, 2 months of the summer drought period, May to September, will average less than 1 inch of rain. In addition to the normal period there was a wet year when rains were nearly double the 22-year average of 55 inches and with only 1 drought month with less than 1 inch of rainfall. Likewise, there was a drought period based on parts of the calendar years 1948 and 1949, for which the effective drought period, all in 1949, covered 4 months with less than 1 inch of rain monthly. The experiment covered 10 ratoons, the performance of which have been separated into the designated three types of rainfall periods.

The yield data show that yields varied directly with the adequacy of rainfall, being highest in the wet period when lack of moisture probably was never a limiting factor, and lowest during the drought period when yields were roughly cut in half because of insufficient moisture. The highest yield, secured in the wet year, was a little more than 15,000 pounds of dry matter containing nearly 1,300 pounds of crude protein when 80 pounds of nitrogen were applied for each ratoon and without renovation. The corresponding yield for the normal year was 11,400 pounds of dry matter, and for the drought year, nearly 8,200 pounds.

With respect to the value of periodic renovation or tillage in which most of the sod cover is more or less destroyed, the topsoil is broken up and stirred by discing, the yield data for the 3-year period show a statistically significant average loss of 23 percent for renovation. Only the unfertilized check benefited from renovation, to the extent of a 44 percent yield increase. Segregation of the data into rainfall periods indicates further that it was only during wet periods that check renovation produced a yield increase. The effect of season is illustrated in figure 8. Wherever nitrogen was applied during the wet year and for all treatments in the normal and drought years, renovation resulted in yield losses ranging up to 20 percent in wet years and up to 38 percent in dry years. For the normal year, the equivalent of one ratoon was lost due to the fact that recovery of the renovated area was slowed by the tillage; hence the yield loss in that year went up to 64 percent of that of the untilled area.

The yield losses resulting from renovation are not statistically significant for every treatment, primarily because of insufficient replication. However, when all treatments in each tillage group are combined, the loss for renovation exceeds the limits of statistical significance, as shown. Inspection of figure 9 shows that in a wet year a yield increase equivalent to that caused by renovation of the check could be obtained by about 50 pounds of nitrogen per acre per year added to the nontilled check treatment. Furthermore, yields for the individual ratoons, not shown in the tabulated data here presented, showed that check renovation increased yields only in one of the four ratoons of the wet year, that grown from the middle of April through August. The remaining ratoons showed no response to renovation. It appears, therefore, that renovation gives increased yields of paspalum only under special circumstances when the supply of available nitrogen is at a very low level, as in the check treatment, and then only in wet seasons when the moisture supply is ample, and then again only in periods of long daylength. On the contrary, renovation is highly detrimental in normal or dry seasons regardless of nitrogen supply, and in wet seasons when nitrogen deficiency is less than acute. It is concluded, therefore, that paspalum sod renovation will be unprofitable except in cases where the stand has been depleted and requires replanting.

With regard to variation in timing of nitrogen fertilization, the yield data show nonsignificant increases result from applying a given treatment in one application every other ratoon as compared with half the amount for each ratoon over a 3-year period (table 12). The yield increase for nitrogen at alternate ratoons in dry seasons, amounting to 24 percent as an average of all nitrogen levels, suggests that the delayed double dose may be more productive for paspalum under drought conditions. It should be noted, however, that the delayed doubled dosage results in a rhythmic yield fluctuation from ratoon to ratoon, yields being nearly doubled when nitrogen is applied and much reduced for the preceding and following ratoons receiving no nitrogen, which confirms the low residual effect of nitrogen on grasses.

In addition to the over-all response to nitrogen fertilization, there is a marked seasonal fluctuation in yield of paspalum which is reflected in higher yields in summer when temperature and daylength hours are near the maximum, and there are greatly lowered yields for all treatments during the winter months when daylength and temperature are near the minimum (figure 8). These seasonal fluctuations find their greatest expression when all other growth factors are optimal. Moisture usually being a critical factor, wet years give high summer yields while dry years show little or no fluctuation in yield associated with daylength. Similar associations of yield with changing daylength were shown to occur with alfalfa at the Poamoho Station, Oahu *(39)*, and are also illustrated for napiergrass at Keaau Ranch, Hawaii, in the present report.

It will be noted from the performance data that the protein content of the soilage remained relatively constant. Statistical analysis of the data shows that none of the various treatments had any significant effect on the percentage of protein in the dry matter. Only in the case of the check yield in the wet year when the protein percentage dropped by about 25 percent while the dry matter yields increased by 126 percent is there any noticeable shift in the protein values. It is evident that nitrogen fertilization had little effect on the percent protein in the dry matter, the prevailing protein content ranging from 8 to 9 percent.

Based on the relatively poor yield performance of paspalum as shown for the droughty and normal rainfall periods as compared with panicum or napier yields recorded in this report, it is evident that paspalum cannot compete with these more productive grasses where rainfall is a seriously limiting factor under conditions similar to those at the Haleakala Station. It is evident also that at this site paspalum is a poor producer in the presence of summer drought, likewise when the daylength factor falls below 11 hours, and again where nitrogen availability is low.

The efficiency of paspalum in converting added nitrogen into protein is shown by the data on percent nitrogen recovery in the yield increment (table 11). Sod renovation for the 3-year period of the test reduced the efficiency of the added nitrogen by 20 to 57 percent below that of the untilled treatment. The efficiency of the added nitrogen ranged from 57 to 75 percent in the wet season on untilled paspalum. It was slightly lower in the normal season. In the dry season the nitrogen efficiency dropped to 29 to 54 percent. The reduction in nitrogen efficiency results from lowered yields under limited rainfall conditions, and is not a result of any loss in the protein percentage. The ability of paspalum to convert added nitrogen into plant protein in this test is about average for grass species, and it falls short of the nitrogen conversion efficiency shown by panicum in this report.

Grazing Performance of Fertilized Pigeonpea–Grass Mixtures, Haleakala Branch Station, Maui

The grazing performance of rhodesgrass *(Chloris gayana* Kunth) and molassesgrass *(Melinis minutiflora* Beauv.) in combination with pigeonpea *(Cajanus cajan* (L) Millsp.) grown under various fertilizer treatments at the Haleakala Station at varying intervals from 1942 to 1945 is presented in table 13. The objective of these experiments was to ascertain the performance of mixed pigeonpeas and grass under rotational grazing pressure.

In this series of tests the rhodesgrass and molassesgrass were interplanted in separate ¼-acre paddocks with the legume pigeonpea, the pigeonpeas being planted in double rows 3 feet apart with 6 feet between pairs planted to grass. Grazing of the pigeonpea–grass mixtures was regulated primarily by the condition of the pigeonpeas, grazing being permitted when the major part of the pods were well filled in the spring and early summer. At other seasons when there were no pea pods, the grazing was started at the preheading stage of the grass component. The pigeonpeas were cut back to a height of 2 feet following the last grazing after setting of seed pods. The cattle used for grazing were long yearling Holstein heifers weighing from 400 to 600 pounds. The stock had free access to water, salt, and bonemeal.

All tests were conducted in duplicate ¼-acre paddocks. Fertilization at the start consisted of a subsurface blanket application of the phosphorus and potassium materials and one-half of the nitrogen treatment according to plan. This was repeated annually as a surface treatment in the fall. The remaining half of the nitrogen was topdressed in the spring following a grazing.

The small size of the paddocks and the shifting of test animals among test plots unfortunately preclude any reliable data on grazing capacity and animal weight gains. Consequently, the best measure of the crop performance under this grazing regime is given by the yields of forage. Yields were taken in triplicate from randomized plots before grazing and from the residue after grazing, the difference being considered to represent the forage eaten by the livestock. Only composite samples from the NPK plots were retained for laboratory analysis, and the dry matter data from these have been utilized in estimating the dry matter yields of all test treatments. The yield performances have been adjusted to an annual acre basis, and as seasonal factors, especially rainfall, were found to react differently, the results have been presented separately by years.

Based on the data on dry matter eaten (table 13), it can be seen that the rhodesgrass and molassesgrass were consumed in about the same amounts, also that the proportion of the eaten to the available forage was greater in dry or droughty years for the rhodesgrass. Likewise, it is evident that pigeonpeas were more efficiently utilized with the rhodesgrass than with the molassesgrass, and that this increased utilization of the pigeonpeas largely accounts for the superiority of the rhodes combination over the molassesgrass combination. It can be seen that the seed pods of the pigeonpea were readily eaten; only in the case of the normal rainfall 1943 season, when grown with molassesgrass, did the stock fail to eat all available pods. Under the same conditions the stock also refused to eat any of the pea foliage. In droughty seasons, however, pigeonpea foliage is consumed at rates ranging up to 59 percent of the total available, whereas the grazing efficiency of associated grasses reaches only 34 percent. Nevertheless, in every year, with the exception of the rhodes combination in the normal rainfall year of 1943, grasses usually produced at least twice as much grazeable forage as the legume. It is evident that the pigeonpea with its 14 to 18 percent protein provided the means for a more desirable nutritive balance in the ration than could be rendered by the grass alone with its 5 to 7 percent protein content. This factor is more important in droughty seasons when the protein content of both the pigeonpea and the grass fractions were lower than in seasons of more ample rainfall.

While no figures are presented in the yield table, data were taken also on the trampling damage and the death of pigeonpea stems during the course of the experiment. The data on stem mortality showed that with the beginning of the third year, following a year of limited rainfall, the pigeonpea stands were so badly depleted that they had essentially ceased to be effective components in the forage mixtures, and therefore caused the tests to be abandoned. The 2- to 3-year effective life of pigeonpea stands at the Haleakala Station is obviously too short to justify the expense of establishing the crop, especially when the utilization is no greater than shown in these tests. The early mortality of pigeonpeas under pasture conditions at the Station is primarily a result of grazing and trampling inasmuch as ungrazed stands retain their vigor for several years even during droughty years.

The data clearly show that under the conditions existing at the Haleakala Station, that for the rates used, fertilization with N or NPK on the pigeonpea–grass combinations is unprofitable. Treatment with P and K results in no increased return over N alone. It was noted that following the initial treatment with the NPK at the start of the experiment, that this treatment outyielded the check or nitrogen treatment by amounts of 1,000 to 3,800 pounds of dry matter for the molassesgrass and rhodesgrass in the first harvest, which required 215 days to produce. This difference in response in favor of the NPK treatment was purely temporary, however, and was not noticed in any subsequent crops. In later ratoons the check and nitrogen treatments overtook the initial rapid development ascribed to the PK components. On the basis of later information it appears that both P and K were too meager to elicit much yield response, much heavier rates of P and K being required initially to overcome the high rate of fixation in the Makawao soils. The data appear inconclusive on the interaction of fertilization and rainfall on yield. Tentatively, it appears that lowered yields associated with droughty years tended to reduce or eliminate response to fertilizers, this being especially noticeable in the performance of pigeonpeas.

SUMMARY

The response of six grasses and two legume–grass mixtures to various rates of nitrogen is reported for nine dryland field experiments. Napier and panicum produced the highest yields and gave satisfactory yield responses at up to 300 pounds of nitrogen per acre per year. Napier was outstanding in maintaining grazing capacity and yields at about 90 percent of normal during drought years with the May-to-September period averaging less than 1 inch of rain per month. The check produced 162 cow-day units of grazing, 9,050 pounds grazeable dry matter, and 610 pounds protein per acre. Nitrogen at 280 pounds produced 437 cow-days, 18,000 pounds dry matter, and 1,660 pounds protein per acre per year.

Applying nitrogen to alternate ratoons of paspalum as compared to nitrogen at each ratoon gave yield increases in drought and normal years ranging from 25 to 40 percent for the alternate method. In wet years there was no gain. Kikuyu, paspalum, rhodes, and molasses grasses were inferior in production to napier and panicum and gave lower returns for nitrogen fertilization.

Small treatments of phosphorus and potassium as additives to nitrogen produced significant gains in only one test. In all four tests receiving the two minerals, the small yield increase would probably fail to justify the expenditure. In one test on mixed pigeonpea and grass, the two minerals gave marked yield stimulation in the first crop but showed no residual effect on subsequent ratoons.

In all experiments where the growing period was sufficiently short to reflect differences in seasonal daylength and temperature, the short-day period produced yields of less than 30 pounds of dry matter per acre per day, compared to about 70 pounds for the long-day period when rainfall was adequate. In drought years limitation of water reduced the stimulating effect of long daylength. In some instances summer drought halted growth almost completely for periods of several weeks.

Annual renovating and crown pruning of dense sods of napier and paspalum resulted in yield losses ranging up to 35 percent of the dry matter. Renovation losses were highest in dry years and were reduced in wet seasons and when heavy rates of nitrogen were applied.

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APPENDIX

TABLE 1. Yield of soilage on nitrogen fertilized kikuyu pasture, Paanui, Haleakala Ranch, Maui, 1947–49[1] (Performance adjusted to annual acre basis. Plots randomized in blocks, replicated five times.)

Treatment	Dry matter per acre			Protein in DM		Adjusted yield increment[3]		Fertilizer cost for DM increment[4]
nitrogen[2]	Test	Adjusted	Adjusted	Test	Adjusted	DM	Protein	
P/A	*P/Y*	*P/Y*	*P/Day*	%	*P/A*	*P/A*	*P/A*	*$/T*
0	3,187	2,700	8	10.6	313	0	0	0
40	3,940	4,080	12	10.6	428	1,380	135	8.70
80	5,146*	5,400	15	9.8	528	1,320	219	9.09
160	7,514*	7,750	21	8.9	707	2,350	381	10.21
320	11,685*	11,570	31	8.7	970	3,820	664	12.57
*LSD at 0.05 probability[5]	1,784							

[1]Test established September 25, 1947. Data on annual basis for four ratoons harvested November 21, 1947, March 31 and August 30, 1948, January 26, 1949. Yield dried at 100° C.

[2]Site an old stand of kikuyu grass plowed March 1947. Half annual treatment broadcast after mowing and removal of yield. Half rate repeated March and October.

[3]Adjusted yields obtained from yield curve derived through applying exponential equation $y = M(1 - R^x)$ to the yield data.

[4]Nitrogen source ammonium sulfate, 20 percent N. Cost of N based on urea, 46 percent N, at $.15 per lb. N.

[5]Least significant difference between yields required for statistical significance at the 5 percent level of significance.

TABLE 2. Yield of soilage on old panicum topdressed with various fertilizers, Koolau Dairy, Oahu, April to December, 1941 (Treatments randomized in blocks, four replications.)

Treatment per year[1]	Yield, Apr.–Dec. DM	Annual performance					
		DM	DM	DM increase over ck	Protein in DM	Protein	Fertilizer cost for DM increase[2]
P/A	*P/A*	*P/A*	*P/A/Day*	*P/A*	%	*P/A*	*$/T*
0	10,651	14,450	40	0	4.58	662	0
P	11,677	15,840	43	1,390	4.90	775	–
NP	15,838*	21,490	59	7,040	4.91	1,054	11.72
NPK	14,832	20,125	55	5,675	4.79	963	–
N_2	18,424*	25,000	69	10,550	5.26	1,316	4.26
N_2PK	19,487	26,440	72	11,990	5.60	1,482	–
N_2PKL	18,789	25,490	70	11,040	5.13	1,307	–
N_4PK	22,690*	30,790	84	16,340	6.56	2,020	10.34
*LSD at 0.05 probability	1,471	1,996	6				

[1]Treatments: N = 50, N_2 = 100, N_4 = 200 pounds per acre per year, applied one-third after every other harvest.
P = 200 pounds P_2O_5 or 88 pounds P.
K = 100 pounds K_2O or 83 pounds K.
L = 1 ton of agricultural lime at start of test.

[2]Cost of fertilizers per ton: Ammonium sulfate, 20 percent N, $90; substituting for urea, 46 percent N, $138 per ton applied, reduces N cost by 33 percent.
Superphosphate, 20 percent P_2O_5, $60.
Potassium sulfate, 52.5 percent K_2O, $95.
Lime, $5.

TABLE 3. Grazing and yield performance of nitrogen fertilized panicum, 5-year average, Haleakala Branch Station, 1947–51 (Results adjusted to annual acre basis. Treatment single ¼-acre paddocks.)

Treatment[1] nitrogen		Grazings per year	Cow-days per acre per year (1,000# unit)	Grazeable yield per year[2]		Protein in DM	DM increase per N increment	Cost of[3] N per DM increment
Per grazing	Per year			Dry matter	Protein			
P/A	*P/A*	*No.*	*No.*	*P/A*	*P/A*	*Percent*	*P/A*	*$/Ton*
0	0	3.2	137	4,400	296	6.73	0	0
30	114	3.8	292	12,451	1,132	9.09	8,051	4.25
60	252	4.2	302	14,133	1,811	12.81	1,682	24.61
90	528	4.4	311	14,353	2,407	16.77	220	376.36

[1]Treatment consisted of ammonium sulfate topdressed after each grazing.

[2]Grazeable yield estimated from difference of plucked new growth in replicated cages compared to yield of residue following grazing.

[3]Cost based on nitrogen from urea, 46 percent N, $138 per ton applied, equals $0.15 per pound N.

TABLE 4. Effect of rainfall on the performance of nitrogen fertilized panicum pasture, Haleakala Branch Station, 1947–51 (Data adjusted to annual acre basis. Treatments single ¼-acre paddocks.)

Year	Factor	Rainfall[1]		Grazings/year				Cow-days/year				Grazeable dry matter/year				Protein in DM				Cost of N for DM increment			
		Mean	May–	Nitrogen, pounds per grazing[2]																Nitrogen, P/A/Y			
		Annual	Sept.	Ck	30	60	120	Ck	30	60	120	Ck	30	60	120	Ck	30	60	120	50	100	200	300
		Inches		*No.*				*No.*				*Pounds/Acre*				*Percent*				*Dollars/Ton DM*			
Wet year Av. of '47, '48, '50	Nitrogen P/A/Y											0	141	318	684								
	Test	75.4	$>$11.0	4.0	4.7	5.3	5.7	163	358	376	377	5,587	14,525	17,374	16,912	6.80	9.05	12.22	16.60				
	Adjusted[3]							150	370	388	390	5,210	14,430	17,080	17,680					3.38	10.00	20.00	72.00
Dry year Av. of '49, '51	Nitrogen P/A/Y											0	90	180	360								
	Test	33.1	$<$11.0	2.5	3.0	3.0	3.0	92	202	197	212	3,145	9,753	9,460	10,592	6.61	8.84	14.04	16.97				
	Adjusted							80	190	215	220	2,610	9,125	10,460	10,740					3.16	15.01	46.16	1,800.00

[1]Average rainfall for years 1938–60, 55 inches per year. Mean rainfall for 5 months May to September, 11.3 inches; this item used as the point separating the wet and dry years. 1949 and 1951 received less than 6 inches rain during the dry 5-month period.

[2]Nitrogen application varied from year to year with the number of grazings. No basic fertilizer treatment utilized.

[3]The standard exponential yield formula $Y = M(1 - R^x)$, applied to the test data provides the estimates of the adjusted data. These estimates also are the basis for the adjusted yield curves in related graphs.

TABLE 5. The recovery of fertilizer nitrogen in the crude protein of harvested panicum as affected by rainfall, Haleakala Branch Station, 1947–51

Factor	Wet year, rain more than average				Dry year, rain less than half of average			
	Nitrogen added per grazing, pounds per acre[1]							
	Check	30	60	120	Check	30	60	120
Protein in DM, pounds per acre	380	1,314	2,123	2,807	208	862	1,328	1,797
Nitrogen in protein, pounds (Protein/6.25)	61	210	340	449	33	138	212	288
Nitrogen increase over check, pounds	–	149	279	388	–	105	179	255
Nitrogen in fertilizer, pounds	0	141	318	684	0	90	180	360
Nitrogen recovery, percent	–	106	88	57	–	117	99	71

[1]The amount of nitrogen added per year varied with the rate per acre and the number of grazings per year.

TABLE 6. Performance of old stand napier soilage following various topdressed fertilizer treatments, Keaau Ranch, Hawaii, 1936–37[1] (Data for six ratoons adjusted to annual acre basis. Treatments randomized in blocks with five replications.)

Treatment[2]		Fresh material	Dry matter	Protein	Protein in DM	DM increase over check	Fertilizer cost for DM increase[3]	Recovery of added N in DM increase
Plan	N-P-K							
	P/A	*P/A*	*P/A*	*P/A*	*Percent*	*P/A*	*$/Ton*	*Percent*
Check	0-0-0	36,900	7,380	582	7.89	0	0	–
PK	0-60-100	45,280	9,060	639	7.06	1,680	36.78	–
NK	160-0-100	60,240	12,050	984	8.17	4,670	14.95	47
NP	160-60-0	52,040	10,410	941	9.04	3,030	29.04	30
NPK	160-60-100	56,760	11,350	912	8.04	3,970	27.66	40
N_2PK	320-60-100	78,000	15,600	1,417	9.08	8,220	19.20	41
LSD at 0.05 probability		4,920	829	68	1.60			

[1]Napier harvested in immature stage at intervals of 61 to 90 days. Growing period about half normal required for full vegetative growth, produced feed of good quality but reduced yield.

[2]Treatment topdressed: N, 32 pounds each ratoon; P and K, one-half annual rate each in April and July.

[3]Fertilizer cost per ton: Urea, 36 percent N, at $138. Using N from ammonium sulfate, 20 percent N, at $90, increases N cost over that of urea by one-half. Superphosphate, 9 percent P (20 P_2O_5), at $60. Potassium sulfate, 44 percent K. (52.5 K_2O), at $95.

TABLE 7. Performance of grazed napier grass with subsoiling and nitrogen fertilization, 4-year average, Haleakala Branch Station, 1945–49[1] (Data represent 10 ratoons, adjusted to annual acre basis. Each tillage nitrogen treatment replicated four times. Subsoiling by blocks.)

Tillage treatment	Factor[2]	Dry matter						
		Nitrogen, pounds per acre						
		Check	48	96	192	288	192PK[3]	Mean
		Pounds/A/Year						
None	Test	9,937	10,904	13,616	17,743	20,401	19,320	15,317
	Adjusted	9,400	11,760	13,750	17,420	20,280	–	–
	Test	6,174	8,780	12,317	15,669	20,406	18,058	13,567
Subsoiled annually	Adjusted	6,450	9,150	11,760	16,210	19,750	–	–
Loss for subsoiling, percent	Adjusted	31	22	14	7	3	–	–
LSD at 0.05 probability	Fertilizer		5,185					
(on test results)	Tillage							5,989

Tillage treatment	Factor	Mean percent protein in DM						
		Nitrogen, pounds per acre						
		Check	48	96	192	288	192PK[3]	Mean
		Protein, percent						
None	Test	5.60	5.58	5.34	5.69	6.25	5.28	5.61
Subsoiled annually	Test	5.65	5.23	5.37	5.66	6.31	5.26	5.49
LSD at 0.05 probability	Fertilizer		1.02					
	Tillage							Not significant

Tillage treatment	Factor	Cost of N per DM increment[4]			
		Nitrogen, pounds per acre			
		50	100	200	300
		Dollars per ton DM			
None	Adjusted	6.25	13.95	16.22	30.00
Subsoiled annually	Adjusted	5.36	11.11	13.04	34.62

[1]New planting of napier grass was annually subsoiled to depth of about 18 inches once each side close to napier rows spaced 4 feet apart following mowing. Yield taken at start of each grazing, average of 2.4 per year, with all plots grazed together followed by mowing of standing trash. Composite sample of all plots of each treatment taken for analysis. Rainfall average or above for 3 years, below average in 1946.

[2]Yields adjusted by application of standard exponential yield formula, $Y = M(1 - R^x)$, to test data. Adjusted data basis for yield curves on related graphs.

[3]Topdressed over row at every ratoon 80–35–166 of NPK (80–100–200 of N–P_2O_5–K_2O), giving annually 192–84–400 pounds of NPK.

[4]Fertilizer cost per ton: Nitrogen from urea, 46 percent, at $138.00. Ammonium sulfate, 20 percent N, at $90.00 increases N cost by one-half. Superphosphate, 9 percent P ($20P_2O_5$), at $60.00. Potassium sulfate, 44 percent K (52.5 K_2O), at $95.00.

TABLE 8. Performance of nitrogen fertilized napier during wet and dry years, (A) each treatment grazed at the optimum vegetative stage, Haleakala Branch Station[1], 1949–51 (Treatments in duplicate, 12 to 14 grazings, adjusted to annual acre basis.)

Year[2]	Factor	Rainfall		Grazings/year				Cow-days/year				Grazeable dry matter/year				Protein in DM				Cost of N for DM increment			
		Mean annual	May–Sept.	Nitrogen, pounds per grazing																Nitrogen, P/A/Y			
				Ck	20	40	60	Ck	20	40	60	Ck	20	40	60	Ck	20	40	60	50	100	200	300
		Inches		*No.*				*No.*				*Pounds/Acre*				*Percent*				*Dollars/Ton*			
Wet, '50	Nitrogen P/A/Y[3]											0	88	176	280								
	Test	82.9	13.5	4.18	4.40	4.40	4.67	266	348	399	468	9,050	12,640	15,770	18,070	6.90	7.68	8.48	9.83				
	Adjusted											8,680	13,170	15,710	17,970					5.84	6.98	10.26	15.35
Droughty, average of '49, '51	Nitrogen P/A/Y											0	72	168	260								
	Test	33.1	<5.0	4.15	3.62	4.21	4.34	212	266	360	418	7,570	10,140	13,570	15,050	7.70	7.68	9.12	9.91				
	Adjusted											7,540	10,480	13,280	15,030					6.86	8.70	11.76	18.75
Droughty period, percent of wet	Test	62	46	99	82	96	93									112	100	108	101				
	Adjusted																			117	125	115	122

[1]Napier yields of dry matter and protein based on grazeable forage only, uneaten residue not included. Grazeable forage plucked by hand consisted of all new leaves and associated stems, optimum growth taken as five new leaves. Yields based on the mean of five randomized caged plots.

[2]Rainfall data for 22 years, 1938–60, mean 55 inches per year, 11.3 inches for 5-month period May to September. Wet year received more than 11 inches rainfall during May–September. Drought year received less than 11 inches rainfall for the May–September period.

[3]Amount of fertilizer nitrogen per year varied with the number of grazings. Basic treatment of 54 pounds P and 264 pounds K per acre applied under the row at start of test.

TABLE 9. Performance of nitrogen fertilized napier during dry year, (B) all treatments grazed simultaneously at the vegetative stage optimum for nitrogen 40 pounds per grazing, Haleakala Branch Station, 1951–52[1] (Treatments in duplicate, seven grazings, adjusted to annual acre basis.)

Year	Factor	Rainfall		Grazings/year				Cow-days/year				Grazeable dry matter/year				Protein in DM				Cost of N for DM increment			
		Mean annual	May–Sept.	Nitrogen, pounds per grazing																Nitrogen, P/A/Y			
				Ck	20	40	60	Ck	20	40	60	Ck	20	40	60	Ck	20	40	60	50	100	200	300
		Inches		*No.*				*No.*				*Pounds/Acre*				*Percent*				*Dollars/Ton*			
Droughty, parts of '51, '52	Nitrogen P/A/Y											0	79	159	238								
	Test	34.2	<5.0	3.97	3.97	3.97	3.97	189	274	374	453	7,450	11,830	15,070	18,260	6.90	7.60	8.60	9.27				
	Adjusted											7,320	12,070	15,430	17,780					4.64	5.79	9.46	10.75
Droughty period, percent of droughty '49, '51 (table 8)	Test	103	–	96	110	94	91	89	103	104	108					90	99	94	94				

[1]This test is a continuation of the test reported in table 8 and differs from this in the timing of the grazing period. For control details see table 8. Grazing geared to the 40-pound N treatment resulted in checks being grazed before reaching new five-leaf growth stage and high nitrogen treatments attaining more than five new leaves.

TABLE 10. Grazing performance of nitrogen fertilized napier, 2-year period, Kaupo Ranch, Maui, 1950–52 (Mean data of two paddocks per treatment, adjusted to annual acre basis.)

Factor	Nitrogen treatment	Cow-days grazing (1,000# unit)	Animal weight gains per acre	Weight gain per cow-day unit
	Pounds	*No.*	*Pounds*	*Pounds*
A—Grazing timed to conditions optimum for check napier, first year, 1950–51. Nitrogen, 74 pounds per acre broadcast after every other grazing.				
N treated	132	193	412	2.1
Check	0	128	288	2.3
Increase for N treatment		65	124	—0.2
Increase over check, percent		51	43	
Production increase per 100 pounds of N		49	94	
B—Grazing timed to conditions considered optimum grazing for nitrogen treated napier, second year, 1951–52. Nitrogen, 37 pounds per acre broadcast after each grazing.				
N treated	98	207	358	1.7
Check	0	143	250	1.7
Increase for N treatment		64	108	0
Increase over check, percent		45	43	
Production increase per 100 pounds of N		65	111	

TABLE 11. Response of paspalum soilage to varying rates of nitrogen fertilization and to renovation, Haleakala Branch Station, 1946–49 (Data for ten ratoons adjusted to annual acre basis. Treatments randomized in blocks, six replications each in nontilled and renovated blocks.)

Period[1] (Rainfall in dry period, May–Sept.)	Tillage[2]	Ratoons per year	Factor[3]	Experimental: Nitrogen, pounds per ratoon[4]: Check	20	20(2)	40	40(2)	80	Average
Wet, 1948 (June <1 inch)	None	3.68	Nitrogen, P/A/Y	0	74	74(2)	147	147(2)	294	
			DM, P/A/Y	977	4,120	4,670	8,659	9,098	15,379	
			Protein in DM, percent	8.39	8.08	8.07	8.12	8.51	8.43	
			Nitrogen recovery, percent	–	57	64	68	75	66	
	Renovated	3.68	DM, P/A/Y	2,209	3,979	4,303	8,229	8,081	13,194	loss 7% for tillage
			Protein in DM, percent	6.29	8.02	8.13	8.11	7.70	8.13	
Normal, 1947 (June, July <1 inch)	None	3.20	Nitrogen, P/A/Y	0	64	64(2)	128	128(2)	256	
			DM, P/A/Y	484	2,468	3,499	5,846	7,333	11,436	
			Protein in DM, percent	8.88	8.71	8.95	8.33	8.62	8.18	
			Nitrogen recovery, percent	–	43	68	56	74	56	
	Renovated	2.20	Nitrogen, P/A/Y	0	44	44(2)	88	88(2)	176	
			DM, P/A/Y	341	1,066	1,310	3,358	3,262	7,644	loss 45% for tillage
			Protein in DM, percent	8.21	7.60	8.70	7.65	8.19	7.49	
Dry, 1946, 1949 (4 months <1 inch)	None	3.03	Nitrogen, P/A/Y	0	61	61(2)	121	121(2)	242	
			DM, P/A/Y	818	2,216	3,114	4,436	5,716	8,177	
			Protein DM, percent	8.80	8.30	8.32	8.45	8.36	8.43	
			Nitrogen recovery, percent	–	29	49	40	54	41	
	Renovated[2]	3.03	DM, P/A/Y	732	1,375	2,028	3,823	4,669	6,672	loss 21% for tillage
			Protein in DM, percent	9.56	8.95	8.19	8.24	8.29	8.62	
Average, 3-year	None	3.30	Nitrogen, P/A/Y	0	66	66(2)	132	132(2)	264	
			DM, P/A/Y	760	2,934	3,761	6,313	7,382	11,672	5,470
			Protein in DM, percent	8.68	8.32	8.40	8.27	8.51	8.34	
			Nitrogen recovery, percent	–	43	61	55	68	55	
	Renovated	2.97	Nitrogen, P/A/Y	0	59	59(2)	119	119(2)	238	
			DM, P/A/Y	1,094	2,138	2,547	5,136	5,337	8,869	4,187
			Protein in DM, percent	7.13	8.04	8.13	7.94	7.93	8.01	
			Nitrogen recovery, percent	–	25	35	44	29	42	
Loss for tillage, percent		10	DM loss	+44	27	32	19	28	24	23
LSD at 0.05 probability			DM, P/A/Y	<—			2,871		—>	1,853

Nitrogen each versus alternate ratoons, no tillage, average two rates, DM, P/A/Y, each ratoon = 4,624, alternate ratoon = 5,572, difference 948
LSD at 0.05 probability 1,853

1, 2, 3, and 4 For footnotes, see table 12.

TABLE 12. Response of paspalum soilage to varying rates of nitrogen applied for each vs. alternate ratoons, Haleakala Branch Station, 1946–49 (Data for ten ratoons adjusted to annual acre basis. Treatments randomized, six replications each in nontilled and renovated blocks.)

Period[1] (Rainfall in dry period, May–Sept.)	Ratoons per year	Factor[3]	Adjusted yield[5]									
			Nitrogen at each ratoon					Nitrogen at alternate ratoons				
			Nitrogen, P/A/Y					Nitrogen, P/A/Y				
			0	50	100	200	300	0	50	100	200	300
Wet, 1948 (June <1 inch)	3.68	Dry matter, P/A/Y Fertz. cost, $/TI	0 –	3,870 3.88	6,970 4.84	11,440 6.77	14,310 10.45	0 –	3,700 4.05	6,650 5.00	10,950 6.98	13,700 10.91
		Av. yield increase	N at each ratoon, 4.5 percent									
Normal, 1947 (June, July <1 inch)	3.20	Dry matter, P/A/Y Fertz. cost, $/TI	0 –	2,980 5.03	5,350 6.33	8,750 8.82	10,970 13.51	0 –	3,150 4.67	5,960 5.34	9,650 8.13	12,040 12.55
		Av. yield increase						N at alternate ratoons, 9.3 percent				
Dry, 1946, 1949 (4 months <1 inch)	3.03	Dry matter, P/A/Y Fertz. cost, $/TI	0 –	2,380 6.30	4,250 8.02	7,020 10.83	8,820 16.67	0 –	2,880 5.21	5,350 6.07	8,750 8.82	10,970 13.51
		Av. yield increase						N at alternate ratoons, 24.0 percent				
Average, 3-year	3.30	Dry matter, P/A/Y Fertz. cost, $/TI	0 –	3,200 4.69	5,700 6.00	9,250 8.45	11,600 12.77	0 –	3,500 4.41	6,200 5.56	10,100 7.69	12,630 11.86
		Av. yield increase						N at alternate ratoons, 10.0 percent. Note that yield increases are indicative, but lack statistical significance.				

[1]Average rainfall distribution at the Haleakala test site shows 2 months in the May-to-September period with less than 1-inch rainfall per month.

[2]Old stand paspalum. Renovated area plowed and disced before experiment started, April, 1946, and again following the fourth ratoon, August, 1947. Tillage resulted in no yield for fifth ratoon on renovation treatment.

[3]DM is dry matter. P/A/Y is pounds per acre per year. $/TI is cost of fertilizer per ton of DM increment.

[4]Nitrogen was topdressed either after each ratoon or after alternate ratoons (2) at double the single ratoon rate. Total nitrogen treatment per year varied with the rate and the number of ratoons as shown.

[5]Adjusted yields are estimated from the standard exponential yield curve $Y = M(1 - R^x)$, when applied to test yields. See related graph. The economy of nitrogen treatment at various levels may be estimated for any assumed value of yield, for the nitrogen treatment cost per yield increments based on N at $0.15 per pound.

TABLE 13. Performance of grazed and fertilized pigeonpea–grass mixtures, Haleakala Branch Station, 1942–45[1] (Performance adjusted to annual acre basis. Mean data for two paddocks sampled in triplicate.)

Year and rainfall distribution	Grazings per year	Forage mixture composition	Total dry matter			DM eaten[2]			Grazing efficiency			Protein in DM
			Check	N	NPK	Check	N	NPK	Check	N	NPK	NPK
			Pounds per acre			*Pounds per acre*			*Percent*			*Percent*
Normal, 1943	2.23	Molassesgrass	5,616	8,023	6,726	1,519	2,994	1,958	27	37	29	6.77
		Pigeonpea—foliage	2,459	1,832	2,164	0	0	0	0	0	0	17.27
(1 month <1 inch)		—pod	984	641	768	648	444	592	65	69	77	
Droughty, 1944		Molassesgrass	7,710	8,192	7,812	1,854	2,221	2,130	26	27	27	4.74
(More than	1.99	Pigeonpea—foliage	743	438	690	346	134	200	47	31	29	13.78
1 month <1 inch)		—pod	278	236	390	278	236	390	100	100	100	
		2-year mean	8,895	9,681	9,275	2,323	3,015	2,635	26	31	28	7.91
Normal, 1943	2.27	Rhodesgrass	6,657	6,422	7,372	1,515	1,913	1,509	23	30	20	7.42
		Pigeonpea—foliage	3,827	3,388	3,182	1,040	1,510	985	27	45	31	15.63
		—pod	545	664	406	545	664	406	100	100	100	
Droughty, 1944	1.96	Rhodesgrass	5,459	6,955	7,558	1,836	2,076	2,473	34	30	33	5.30
		Pigeonpea—foliage	1,402	968	1,191	821	406	374	59	42	31	13.78
		—pod	154	226	105	154	226	105	100	100	100	
		2-year mean	9,022	9,312	9,907	2,956	3,398	2,926	33	36	30	9.00
Increase rhodesgrass over molassesgrass, percent			1	—4	7	27	13	11	27	16	7	14

[1]Rhodesgrass and molassesgrass interplanted with pigeonpea, with pigeonpeas in twin rows 3 feet apart and 6 feet between twin rows. Mixture grazed when pigeonpea pods mature or when grass in preheading stage.

Annual fertilizer treatment consisted of N, 60 pounds per acre as ammonium sulfate broadcast one-half each in spring and fall; P, 26 pounds (60 P_2O_5) as superphosphate; K, 50 pounds (60K_2O) as potassium chloride. P and K disced in at start, thereafter topdressed annually.

[2]Total yields estimated from plots harvested before grazing. Yields of residual forage harvested following grazing. Difference between the two gives forage eaten.

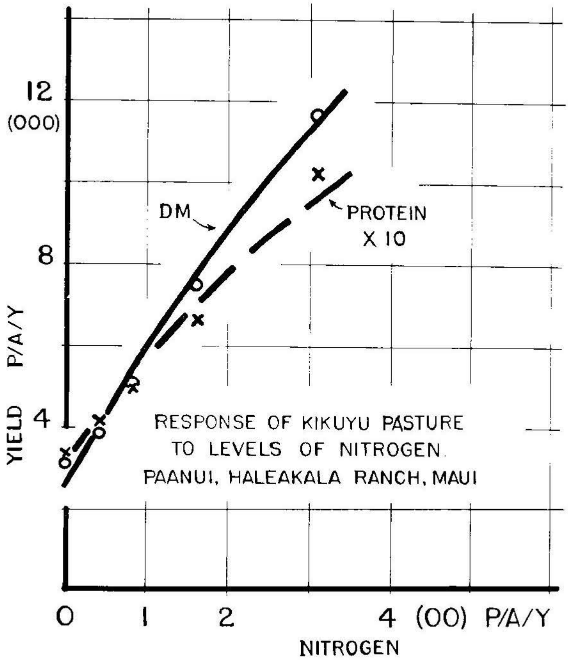

FIGURE 1. Adjusted yield curves, $Y = M(1 - R^x)$, for kikuyu dry matter and crude protein under varying rates of nitrogen treatment. Circles and crosses indicate the actual test yields (see table 1). Paanui, Haleakala Ranch, 1947–49.

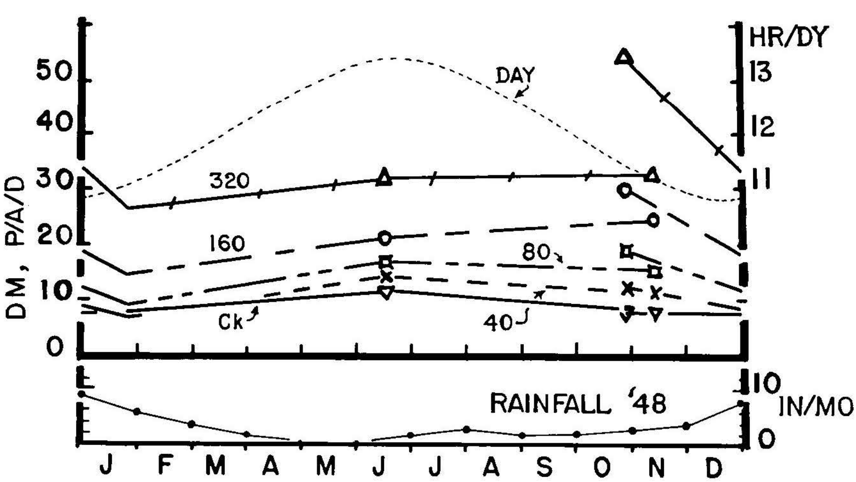

FIGURE 2. Seasonal yield response of kikuyu pasture to varying rates of nitrogen. Low summer rainfall seriously limited growth during the long daylength period. With generous rainfall, yields usually follow the daylength curve. Note that despite lack of rainfall the yield differences for the various nitrogen rates were maintained throughout the year. Paanui, Haleakala Ranch, 1947–49.

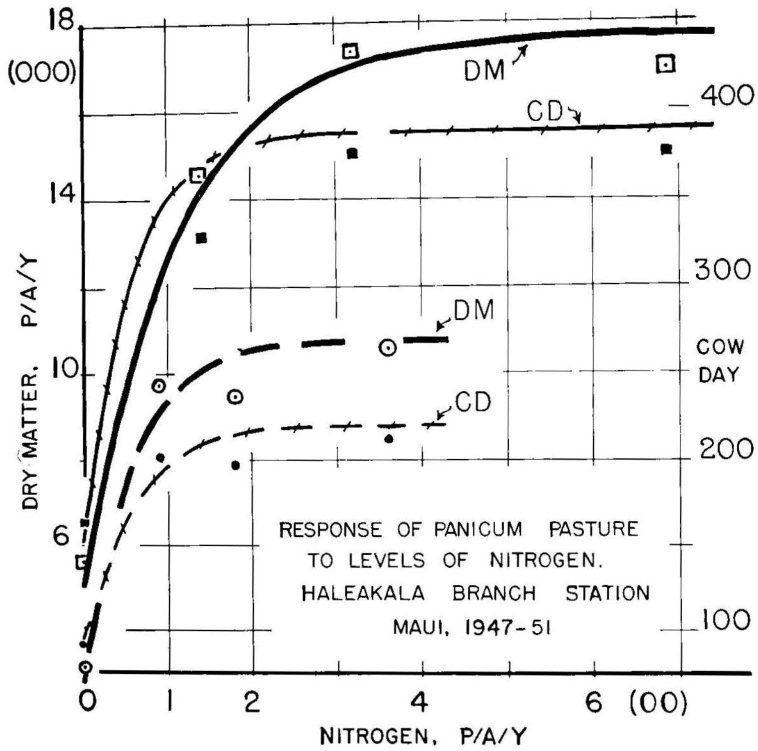

FIGURE 3. Effect of wet and dry years on nitrogen fertilized panicum pasture yield and carrying capacity. Upper solid curves represent wet years and suggest profitable nitrogen treatment at rates to about 150 pounds per acre per year. Lower broken curves represent dry-year yields and indicate profitable nitrogen treatment to the 100-pound rate (table 4).

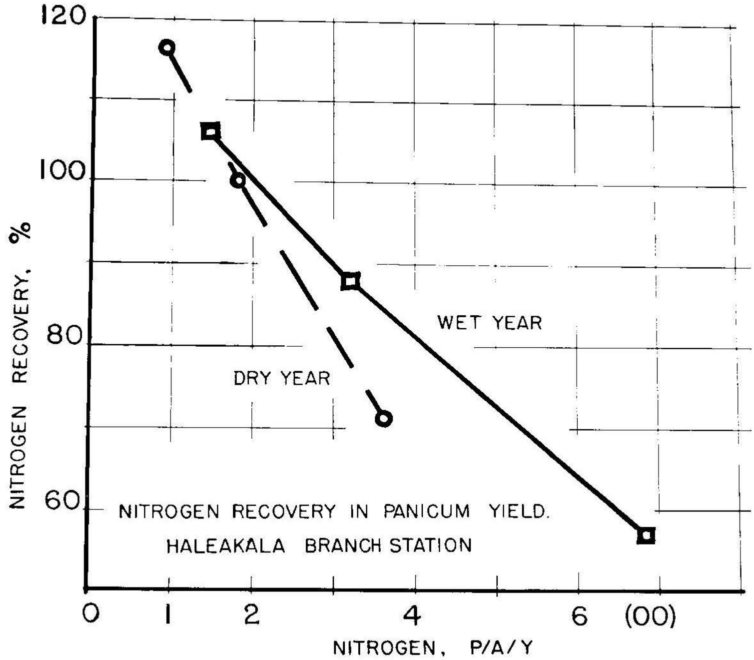

FIGURE 4. Panicum is an extremely efficient user of nitrogen as shown by the high recovery rate of nitrogen in the yield. Most grasses recover less than 60 percent of added nitrogen. Note the importance of adequate water or rainfall as illustrated by the higher nitrogen recovery in the wet year. Haleakala Branch Station.

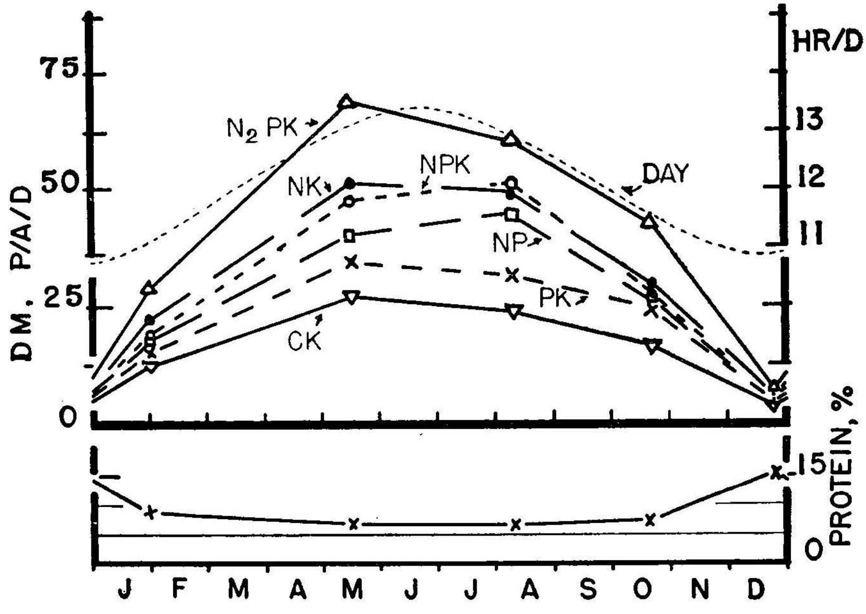

FIGURE 5. Seasonal response of fertilized napier harvested at 60- to 90-day intervals, showing marked variation in yield with daylength. The change in protein content with daylength is actually an inverse relationship of protein to stage of maturity of the napier. Napier normally requires about 120 days for optimum vegetative growth. Keaau Ranch, 1936–37.

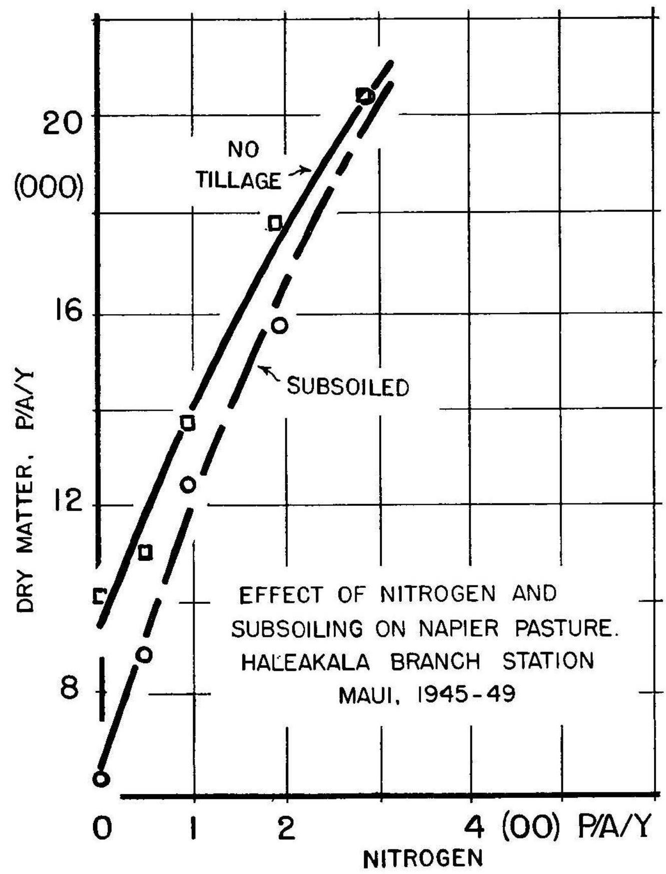

FIGURE 6. Four years of grazed napier showed a marked response to nitrogen. Annual subsoiling of the area between napier rows spaced 4 feet apart produced no yield increase. Test yields are indicated by squares and circles. Haleakala Branch Station.

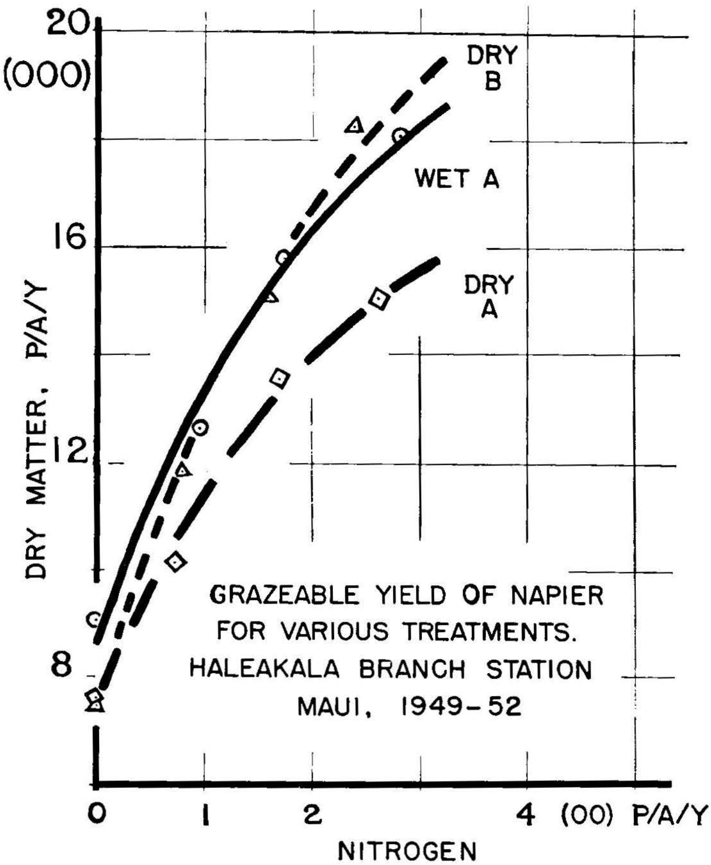

FIGURE 7. Response of grazed napier to nitrogen treatment and to two methods of grazing. In the A method of grazing, each treatment paddock was grazed when new growth on old stems subtended five new leaves. In method B grazing, all treatments were grazed simultaneously when growth in the 40-pound nitrogen rate per grazing attained five new leaves (see tables 8 and 9). Method B grazing favored the high nitrogen treatments with rapid growth and penalized the slower, low nitrogen rates. Haleakala Branch Station.

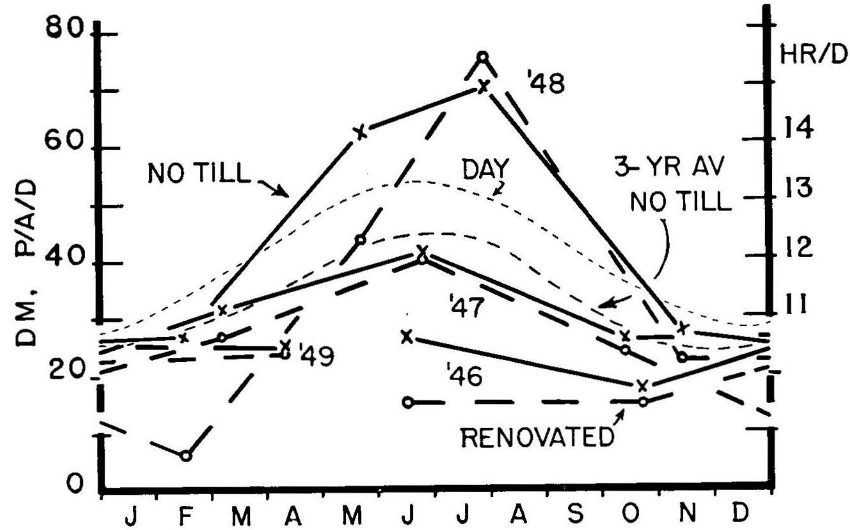

FIGURE 8. Yields of paspalum showing the influence of daylength, season (rainfall), and sod renovation for soilage receiving 80 pounds of nitrogen per acre every ratoon. Note the dominating effect of daylength factors and season on yield. Season 1948 had 1 month, during May to September, with less than 1 inch of rain; 1947 had 2 dry months and 1946 had 4 droughty months. Haleakala Branch Station, 1946–49.

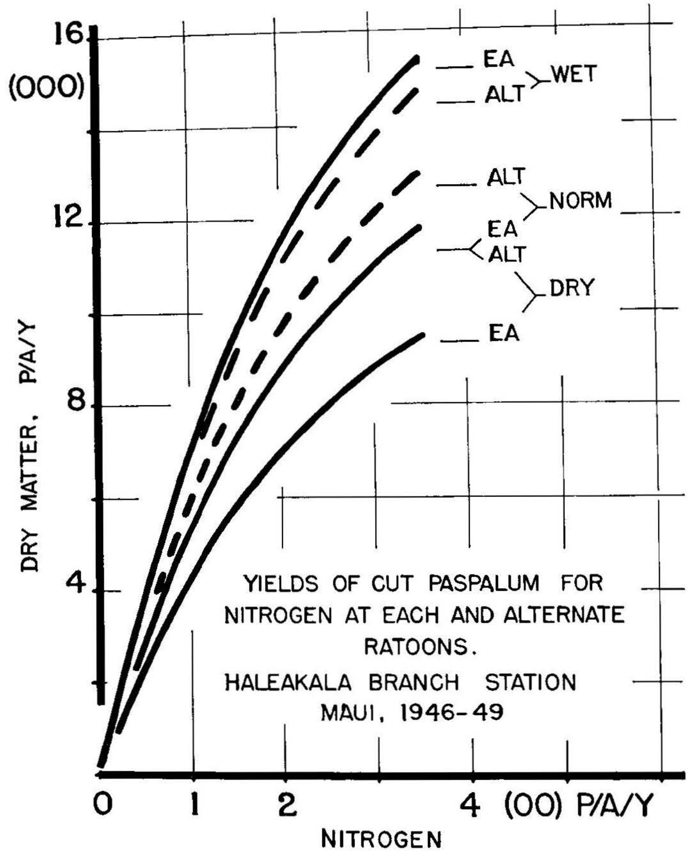

FIGURE 9. Effect of rainfall on yields of paspalum soilage for varying rates of nitrogen applied at each and at alternate ratoons. Nitrogen at alternate ratoons gives greater yields in dry years. In wet years, timing of nitrogen treatment is immaterial. Note continuing high yield response to nitrogen in wet years. Nitrogen applied at alternate ratoons gives marked fluctuations in yield because nitrogen has a low residual effect or carry-over to subsequent ratoons.

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